Late-Wisconsin Pollen Stratigraphy in East-Central Minnesota

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ABSTRACT

Reconstruction of the landscape bared by the melting Grantsburg sublobe is aided by pollen diagrams from three sites. At Horseshoe Lake and Cedar Bog Lake, on the Anoka Sand Plain, the pollen spectra above a thin basal layer of plant detritus are dominated by Picea, but other conifers (except Pinus), deciduous trees (especially Populus, Fraxinus, Betula, and Quercus), and herbs (chiefly Cyperaceae, Artemisia, and Ambrosia-type) are well represented. Comparison of the pollen flora of this late-Wisconsin zone with modern floristic provinces emphasizes its complexity. Although plants now common to the Boreal and Great Lakes provinces contributed about one-half of the pollen rain, 35 of the 104 taxa identified belong to deciduous elements, and a prairie element is represented by 6 taxa.

Secondary redeposition of part of the late-Wisconsin pollen flora cannot explain its singularity. At Andree Bog, on the Lake Grantsburg plain, the basal spectra are contaminated by secondary microfossils largely Cretaceous in age, and their subtraction has little effect on the pollen flora. At Horseshoe Lake and Cedar Bog Lake the amount of secondary pollen is negligible.

The available radiocarbon dates indicate that some lakes on the Anoka Sand Plain were open as early as 12,500 radiocarbon years ago but that melting of buried ice may have continued for as long as 1000 years. On this unstable surface a mosaic of forest and openings is visualized, with Picea, Fraxinus, Populus, and other deciduous trees on moist sites and prairie species in more xeric habitats.

Although unlike any modern example, this postulated vegetation is most analogous to the aspen parkland of southern Manitoba.

The Picea-dominated zone is succeeded abruptly by a zone characterized by Pinus, spores of Pteridium aquilinum, and abundant Betula, Ulmus, and Quercus pollen; it is radiocarbon-dated at 11,000 years BP. Pinus decreases in importance higher in the sediments, and pollen of grasses and composites becomes more abundant. At Cedar Bog Lake Ulmus is an important component early in this high-NAP zone, together with other taxa suggesting the presence of mesic forest. At a higher level, dated at 8,000 years BP, these taxa decrease, and the sediment lithology and pollen spectra suggest that the lake became shallow. Quercus dominates the tree pollen in the remainder of the sediments; Compositae pollen decreases above a zone boundary dated at 4,500 years BP, and the local bog forest apparently developed at about that time.

The peculiarities of the late-Wisconsin flora may be explained by a climate different from any known today within the range of the taxa involved. Summers may have been cool and dry, but the mean annual temperature may not have been different from that in northern Minnesota today. There is little evidence in the pollen diagrams of a cooler period corresponding to the Valders glacier readvance. Instead, the present interpretation suggests a gradual warming through the late Wisconsin, with perhaps a more abrupt rise in summer temperature at the end of deposition of the Picea-dominated zone.

That interval which saw the disappearance of the latest of the Pleistocene ice sheets has without doubt been studied more intensively by geologists than any other time span of comparable length. This disproportionate attention results largely from interest in the enigmatic causes of the wastage of the ice sheets. What was the nature and magnitude of the climatic change that accompanied the disappearance of the ice? Was it synchronous over the earth? What were the geographic variations in the climate? To what extent was the climate near the ice margin affected by the presence of the ice itself? Were there pronounced climatic fluctuations during the period of general deglaciation and, if so, what effect did they have on the ice sheet? These and similar questions are relevant to the understanding of not only the conditions of man's past but also the trends in his present environment.

The answers to these questions are evolving rapidly at present. By nature the questions are synthetic and demand the prior accumulation of data from many limited areas over the earth. Further, since past climate itself cannot be measured, its reconstruction must depend on inference from observations of the physical records dating from the period of interest, and often the inference depends on only a limited comprehension of complex systems. As both new data from past records and understanding of present processes increase, our concepts of past climate and climatic change will thus be continually modified.

Almost any isolated observation of the stratigraphic record, whether it be geologic, pedologic, or biologic, can become the basis of an inference about past climate. Some of the inferences made from

such isolated observations will have a higher probability of truth than others, and clearly a group of inferences that agree will permit more assurance than any one independently. When information is limited and scattered, the temptation is great to combine independent inferences in the reconstruction of past climate and, in doing so, to rely more heavily on those inferences that support one another than on those in disagreement. Although it may be necessary at times, such a procedure is dangerous because it tends to encourage the reinterpretation of observations to fit the developing climatic model; it thus fosters a circularity of argument.

This circularity can be forestalled by delaying the formulation of the climatic model until after the accumulated observations have been fitted together to make a coherent picture of past conditions. Such a distinction can be maintained by emphasizing the reconstruction of landscape rather than the reconstruction of climate. If the paleolandscape of an area, which includes its topography and the organisms that populated it, can be determined from the direct evidence of sediments and fossils, the interplay of forces within that landscape--the ecosystem--can be inferred, and it is at this level of reasoning that notions of paleoclimate properly enter.

The present study is conceived as a test of the applicability of pollen analysis to the task of reconstructing the landscape of a portion of Minnesota during the wasting of the Wisconsin ice sheet. The glacial geology of the area chosen is well understood; the best regional summaries are by Cooper (1935) and Wright (1956). The existence of this firm background permits the focus of attention to be brought to the vegetation and the physiographic processes within the area bared by the melting ice. When these aspects of the landscape

are understood, their relation to the movements of the waning ice sheet and to the regional climate will lead us to a greater appreciation of the Pleistocene.

Terminology

Because care is being taken to keep the changes in pollen stratigraphy and the changes in glacier position distinct until evidence to prove how they are related in time is available, I have deliberately avoided the time-stratigraphic units and geologic-climate units generally used by glacial geologists in discussing the pollen evidence. The precise application of the common informal terms "late-glacial" and "postglacial" presents a more difficult problem. To many glacial geologists, the term "late-glacial" as applied in a certain glaciated area includes that time between the first appearance of the land surface from beneath the wasting ice to the final disappearance of active ice from the area; the term was given a specific local sense by, for example, West (1961, p. 766). To others concerned with pollen analysis (for example, Deevey, 1951, p. 198), the boundary between late-glacial and postglacial is placed at the time of a local inferred vegetation change; this is probably the most common usage in northern Europe, where the two definitions are to some extent reconcilable (Nordmann, 1928, p. 121). Still others (for example, Heusser, 1960, p. 245) define the late-glacial on the basis of inferred climatic change.

To prevent confusion, it seems best to restrict the term "late-glacial" to that time during which active glacier ice was disappearing from the area of concern; "postglacial" then applies to subsequent time in the area, in accordance with the suggestion of Flint (1957, p. 283). The time of existence of inferred vegetation units

may be adequately described by the pollen zones in sediments in the area; one may thus speak informally of "Picea-Larix time" to embrace that interval during which the Picea-Larix assemblage zone was deposited.

Time-stratigraphic boundaries of widespread applicability are as yet poorly defined within the Pleistocene and Recent Series. The term "late-Wisconsin" is here used informally and loosely to designate a period of time with an undefined lower boundary within the Wisconsin Age and with an upper boundary defined in east-central Minnesota by the upper boundary of the Picea-Larix pollen assemblage zone.

Plant nomenclature in this study follows Fernald (1950); authors of plant names are cited only when the names do not appear in that manual, and then only the first time the names are used.

METHODS

Sampling

Samples for pollen analysis from the three sites described here were taken during the period 1958 to 1960. A core sampler with stationary piston, similar to the one described by Livingstone (1955) as modified by Vallentyne (1955) and Rowley and Dahl (1956), was used for most of the sampling. The sampling was done from the frozen lake surface (at Horseshoe and Cedar Bog Lakes) or from the bog surface (at Andree Bog); a drive frame with chain hoists was used effectively to sample sediments at depth (Cushing and Wright, 1963).

A nearly continuous set of core segments from a single borehole was obtained for pollen analysis from both Horseshoe Lake and Andree Bog. The sequence of sediments from Cedar Bog Lake used for pollen analysis is a composite from four adjacent borings. (See the core segment column of figure 3.) Correlation between the cores is based on lithology. The lower four meters of organic sediment could not be penetrated with the piston core sampler on the first sampling attempt, and a Davis peat borer was used to obtain the samples. Later a nearly continuous core to the bottom of the organic sediments was obtained from a nearby single borehole, and the stratigraphy on which the correlation of the pollen cores was based was verified.

Core segments were normally extruded and the sediment described in the field. They were then wrapped in aluminum foil for transport to the laboratory, where they were opened, the sediment redescribed in detail, and samples taken for pollen analysis.

Sediment description and nomenclature

The system of Troels-Smith (1955) provides an objective and complete method for the field description of fresh-water sediments. It was adopted, with slight modification, for this study. The proportion of the component elements of the sediment were noted, together with the color, degree of softness, elasticity, calcareousness, and nature of contacts. The degree of softness is a four-part subdivision (from very soft to very firm) of Troels-Smith's siccitas 1 and 2; it is related to the water content of the sediment. The degree of calcareousness was determined by the amount of reaction of the sediment with cold 10 percent hydrochloric acid and ranges from non-calcareous (calc 0, no observable reaction) to extremely calcareous (calc 4, violent reaction). The degree of humicity was tested by boiling a sediment sample briefly in a 10 percent potassium hydroxide solution; a humified sediment turns the extract dark brown, and the degree of humicity was estimated from the color value of the liquid.

The sediment was further characterized by microscopic examination of the residue after chemical preparation for pollen analysis. Various residue components were identified; these included mineral particles (estimated as silt and clay, and only when hydrofluoric acid treatment was not used), pyrite, combined cellular fragments of bryophytes, pteridophytes, or spermatophytes, fungal hyphae, pollen and spores (excluding spores of thallophytes), algae, chitin, and charcoal fragments. The abundance of each of these components was estimated visually and expressed by a five-part scale (abundant, common, infrequent, rare, and very rare). The level of abundance assigned to a given component depended on its relative density compared not only with all other components in the slide under examination but also with

the same component in all other sediment samples studied. The method is exceedingly crude and highly subjective, but it permits the recognition of gross lithologic differences that may be invisible in the field examination of sediments.

The naming of sediment types largely follows the classification given by Swain (1956). The term copropel proposed by Swain and Propokovich (1954) is used in place of gyttja, which is less suitable etymologically. It comprises most of the element Limus detrituosus of Troels-Smith but emphasizes the coprogenic origin of much of the material. Peat is here reserved for the turfa of Troels-Smith; it consists of roots and rhizomes and above-ground plant parts connected to them. Disconnected fragments of plants are termed detritus, also following Troels-Smith. The useful distinction between autochthonous and allochthonous sediments commonly made by European pollen stratigraphers is thus preserved. Siderite ($FeCO_3$), which makes up a significant portion of the lowermost sediments at Cedar Bog Lake (Swain and Prokopovich, 1954), is here included in Troels-Smith's element Limus ferrugineus (Lf).

Preparation of samples

Sediment samples from Horseshoe Lake and Andree Bog were prepared for pollen analysis by the standard concentration procedure summarized below:

1. Treatment with hot 10 percent potassium hydroxide for two minutes.
2. Treatment with 10 percent hydrochloric acid.
3. Treatment with 45 percent hydrofluoric acid, by either of two methods:

a) gentle boiling for five minutes, or

b) digestion in cold HF for 6 to 12 hours.

4. Acetolysis for one minute in a mixture of acetic anhydride (9 parts) and concentrated sulfuric acid (1 part).
5. Staining with basic fuchsin.
6. Mounting in silicone oil, 2000 cs.

The sediment samples from Cedar Bog Lake were prepared in a similar way, except that step 3 was omitted for all but the lowermost four samples, and glycerin was the mounting medium used for the lower 29 samples.

Pollen analysis

Pollen and spores were counted at a magnification of 300X for most of the analyses; a fluorite objective (N.A. = 0.85) was used. For critical identifications and examination of unknown or damaged grains, an apochromatic oil-immersion objective was used at an effective numerical aperture of 0.95 (condenser dry). The same objective, but with the condenser immersed, was used when the highest possible resolution (N.A. = 1.32) was needed. Phase contrast optics (apochromatic oil-immersion objective, N.A. = 1.15) were helpful in studying certain pollen types.

Whole numbers of slides were counted at each level. The pollen counts are tabulated in the appendix, tables 3, 4, and 5.

Choice of pollen sum

The percentages shown in the basic pollen diagrams (figs. 3, 8, and 10) are calculated from the sum of determinable pollen and spores of all vascular plants except those judged to have arrived at the site of deposition by means other than transport through the

atmosphere. For limnic sediments, the site of deposition is here taken to be the open water of the lake, and thus pollen of submersed and floating aquatics is excluded from the basic sum. This choice of pollen sum is based upon the principle of inclusion within the calculation base of all members of the universe, which is here taken to be the atmospheric rain of pollen and spores. The reason for the exclusion of the wind-disseminated spores of thallophytes and bryophytes is chiefly a matter of ignorance of the spore types.

On the other hand, it is frequently desirable to examine only a portion of the pollen rain, usually in order to eliminate the effect of one or more components on the relative frequency of other components of particular interest. For this purpose special sums are used, such as those in the special diagram, figure 4.

Format of pollen diagrams

The basic pollen diagrams (figs. 3, 8, and 10) are uniform in arrangement. The sediment symbols used in the lithology column at the left follow the system of Troels-Smith (1955); they are explained in the legend for the diagram. To the right of the lithology column is shown the position of the core segments from which the pollen samples were taken. Then follows the main diagram, in which the total contribution to the pollen rain of trees, shrubs, and herbs is shown, together with the curves for Picea, Pinus, and (in fig. 3 only) Gramineae. The remainder of the types are shown by silhouette curves. The black curve indicates percentage directly from the scale at the bottom of the diagram; the stippled curve is exaggerated ten times. Next follow the number of grains in the pollen sum, the number of pollen types in the sum, and the curves for types excluded from the sum. The pollen zones are indicated at the extreme right.

The special diagram (fig. 4) is similar. Only selected curves are shown, however, and certain types are omitted from the pollen sum. Pollen types with black silhouette curves are included in the pollen sum; those with white silhouettes have been excluded from the sum at those levels where the curve is white.

Terminology of pollen zones

For ease in referral and discussion, it is often desirable to divide pollen diagrams into zones. These should be defined only on the basis of observable changes in the pollen percentages in the sediment, in order to avoid confusion of meaning. As Andersen (1961) pointed out, a pollen zone so defined is a biostratigraphic unit, which is "a body of rock strata characterized by its content of fossils contemporaneous with the deposition of the strata" (American Commission on Stratigraphic Nomenclature, 1961). As such, a pollen zone traced from one site to another carries no direct connotations of time correlation or climatic equivalence. Because Pleistocene pollen zones are rarely if ever characterized by the unique occurrence of one or more pollen types, they belong to the category of assemblage zones.

The pollen zones used here are consequently defined and named in accordance with the code of stratigraphic nomenclature (American Commission on Stratigraphic Nomenclature, 1961). The zones were defined after examination of all the available pollen diagrams in the region and were named for taxa whose pollen grains or spores are characteristically more abundant in a given zone than in those above and below it. If a choice in the naming of a zone was possible, preference was usually, but not necessarily, given to a combination of names of taxa believed to have some ecological association. The name of an

assemblage zone may thus be suggestive of its fossil composition, but it should be emphasized that the zone is defined by the description that accompanies the name.

The assemblage zones are divided into subzones for further convenience, but, as permitted by the Code, not all intervals within an assemblage zone are necessarily given subzone names. For the sake of brevity in the discussion, the word "assemblage" is omitted from the names of the zones and subzones, but it must be remembered that it is a group of taxa, rather than one or two taxa, that gives the pollen zones their character.

Application of the code of stratigraphic nomenclature to pollen zones has definite advantages over the usual procedure of assigning numerals or letters to the zones. Names provide greater flexibility in use than a sequence of numbers or letters, for as zones are traced across a region names may be inserted or deleted, as new zones appear or drop out, without disrupting the sequence. Because the zone names immediately suggest the composition of the pollen spectra, they facilitate description and precise comparison. Furthermore, because the names refer specifically to the fossil assemblage, they lessen the temptation to consider the zones, without proof, as time-stratigraphic units.

IDENTIFICATIONS

As palynologists and paleoecologists demand more and more information from the analysis of pollen-bearing sediments, growing emphasis is placed on the determination of pollen and spores to the lowest possible taxon. Fortunately, the increasing use of high-quality optical equipment, the introduction of new techniques, and advances in knowledge of pollen morphology have made routine the separation of types that were once considered indistinguishable. Yet it becomes increasingly important to describe and define the new types that are identified, to permit others not only to share the experience gained in making the determinations but also to judge the accuracy of the identifications. Short descriptions of the less common pollen grains encountered in this study are therefore given here, together with the taxonomic limits of many of the pollen types identified.

Conventions

The reliability of identifications is indicated throughout this paper by the use of a set of conventions. If the identification is beyond all reasonable doubt, the unqualified name of the appropriate taxon (be it family, genus, or species) is used. It should then be understood that I cannot now distinguish lower taxonomic levels on pollen-morphological grounds. On the other hand, other arguments than purely morphological ones usually affect the choice of the name given to a pollen type. Chief among these is evidence from phytogeography. If the present range of a taxon together with our current presumptions about plant migration makes it highly improbable that the taxon contributed pollen to the sediments at the sites under study, that taxon

is normally excluded from consideration in naming pollen types, at least until all other taxa whose presence has a higher order of probability have been examined. For example, pollen found in this study that agreed well with reference material of Larix laricina is given the name of that species, even though it is doubtful whether pollen of the western montane Larix occidentalis Nutt., or even the less closely related Pseudotsuga menziesii (Mirb.) Franco, could have been distinguished from it. Since pollen can be transported considerable distances from its source, there exists a finite probability that pollen of any plant in the world may be encountered during pollen analysis, and it is the responsibility of both the palynologist and the critical reader to evaluate the probability of all identifications in this light.

A lower order of certainty in identification is indicated by the abbreviation cf. This abbreviation signifies close agreement between the fossil grain and grains of the taxon whose name follows the sign but also indicates that other taxa of equivalent rank cannot be confidently excluded from consideration. The reason for the uncertainty may include, in addition to the phytogeographical considerations just discussed, close morphological similarity of the grain with those of other taxa, lack of sufficient reference material, or imperfect preservation of the fossil grain. In each case, the reason is explained in the notes on identification.

If only two taxa are thought probable alternatives for the identification of a fossil grain, this is indicated by a virgule between the names (for example, Ostrya/Carpinus, which designates pollen grains referable to either Ostrya virginiana or Carpinus caroliniana, but not to other possible members of the family Corylaceae). If there are more

than two possible alternatives, "-type" is suffixed to the name of one of them, and the identification notes list the other possibilities (for example, Chenopodium-type, which includes many but not all of the genera in the families Chenopodiaceae and Amaranthaceae).

A reference collection of about 2700 slides was available to me at the time most of the identifications were made or checked. Because intraspecific variation in pollen morphology is an important factor limiting the separation of closely allied taxa, the number of separate collections compared in making a determination is relevant to the reliability of the determination. In the following notes, therefore, the number of collections seen is given in parentheses after the name of the taxon. The number of species seen is also given for certain large families within which variation in pollen morphology is small.

In the descriptions I have used the system of morphological terminology proposed by Iversen and Troels-Smith (1950) and, for convenience, the abbreviations suggested by those authors. No attempt has been made to give a complete diagnosis of each pollen or spore type; instead only the features that I consider especially characteristic of the type are given. Where size is given, it refers to measurements of modern pollen treated with 10 percent potassium hydroxide and acetolysis and mounted in silicone oil.

Pteridophyta

Lycopodiaceae.

Lycopodium (8 sp., 13 coll.). The study by Maloney (1961) aided the differentiation of spores of this genus. One spore was assigned to Lycopodium clavatum, eight to L. complanatum-type (including

L. tristachyum), and one to L. selago-type (including L. lucidulum).

Ophioglossaceae.

Botrychium (7 sp., 9 coll.). Three fossil spores agree well with B. lunaria, and one is tentatively referred to B. multifidum. (See Maloney, 1961.)

Osmundaceae.

Osmunda (3 sp., 6 coll.). Two fossil spores with distinct ver are assigned to O. cinnamomea. (See Andersen, 1961.)

Polypodiaceae.

Identifications were aided by Maloney's (1961) study of the spores in this family.

Dryopteris-type. Monolete, psilate spores with perispore lacking or poorly preserved are included in this type. Such spores may belong to species of any of the following genera: Dryopteris, Woodsia, Cystopteris, Onoclea, Polystichum, Athyrium, Camptosorus, and Asplenium.

Dryopteris thelypteris var. pubescens (3 coll.). Several spores with perispore preserved are referred to this taxon. Of about 150 spores counted in a re-examination of the maximum of Dryopteris-type spores in the Dryopteris subzone of the Compositae-Quercus zone at Cedar Bog Lake, three possessed all or part of the perispore and were identified as Dryopteris thelypteris. The remainder agreed well in size and shape with the spores of that species, and it is highly probable that it is responsible for the prominent maximum of spores in the subzone.

cf. Gymnocarpium. Monolete spores without perispore but with a peculiar verrucate exine are included in this type. The ver are low and angular in outline, and the sculpture may well be described

as areolate. As Maloney (1961) pointed out, such an exine sculpture is present in Gymnocarpium dryopteris (L.) Newm. (Dryopteris disjuncta) (1 coll.) and G. robertiana (Hoffm.) Christens. (Dryopteris robertiana). Spores with verrucate exine are also common in our material of Dryopteris fragrans var. remotiuscula (1 coll.) and D. cristata (2 coll.), but in these the ver are rounded and diffuse. Spores of Dryopteris linnaeana Christens., another synonym of Gymnocarpium dryopteris (Hultén, 1962), have been reported from European late-glacial (Krog, 1954) and interglacial (Andersen, 1961) sites. Until more is known of the variability of exine sculpturing in our material, it seems best to keep the identifications tentative.

Athyrium filix-femina (1 coll.). The ver-rug sculpture of this monolete spore is distinctive.

Cryptogramma cf. stelleri (1 coll.). Trilete, ver; ver less distinct from each other than in C. crispa var. acrostichoides (1 coll.). One spore is tentatively assigned to this species.

Adiantum (2 sp., 2 coll.). Trilete, sca. Five fossil spores.

Gymnospermae

Ephedraceae.

Ephedra viridis-type. Colpi with lateral branches extending up the meridional ridges; equivalent to type A of Steeves and Barghoorn (1959). In our material this type includes E. viridis Cov. (3 coll.), E. nevadensis Wats. (1 coll.), E. funera Cov. (1 coll.), E. cutleri Peebles (1 coll.), and E. antisyphilitica C.A. Meyer (1 coll.). Three fossil grains.

Ephedra trifurca-type. Colpi unbranched; equivalent to types D and C of Steeves and Barghoorn. In our material the type

includes E. trifurca Torr. (2 coll.), E. torreyana Wats. (2 coll.), and E. californica Wats. (1 coll.). Two fossil grains agree very well with E. trifurca (ridges broad, rounded, and straight); a third grain agrees better with reference grains of E. torreyana (ridges narrow and slightly undulating). Our reference material is sufficiently variable, however, that it seems best to keep these species together as one pollen type.

The differences between our material of Ephedra and the descriptions of Steeves and Barghoorn are unexplained (especially the characteristics of E. nevadensis and E. californica; compare also the figures of Andersen, 1954); they may reflect the difficult taxonomy of the genus.

Taxaceae.

Taxus canadensis (3 coll.). Grains are similar to the European Taxus baccata L. (Jessen, Andersen, and Farrington, 1959; Beug, 1961).

Pinaceae.

Picea (5 sp., 25 coll.). Both Picea mariana and P. glauca are equally likely to have occurred in the late-Wisconsin vegetation of Minnesota; the presence of other species is improbable. The pollen grains of P. mariana and P. glauca differ slightly in size and shape in our material; P. glauca pollen tends to be larger in all dimensions than P. mariana pollen and to have larger bladders relative to the body of the grain. The amount of variation in these characters is so great in our reference material, however, that it would seem impossible to identify every grain in a mixture of pollen of the two species. On the other hand, the variation in size and shape of the spruce grains

throughout the Picea-Larix zone at my sites is sufficiently large to make it highly probable that both species were present. A size-frequency study of the fossil pollen, like that made by Davis (1958), could be used to test this supposition. In the absence of a rigorous investigation of the variation in reference material, however, such a study seems unproductive and was not attempted here.

Pinus. The present distribution of the pines in North America makes it unlikely that species other than Pinus banksiana, P. resinosa, and P. strobus were present in Minnesota during late- and post-Wisconsin time. The pollen grains of the first two species have a psilate or scabrate tenuitas (a term used by Erdtman (1957) for the distal area of the grain), corresponding to the Diploxylon type of Ueno (1958). Pinus strobus, however, has the distinctly verrucate tenuitas typical of the Haploxylon type of Ueno. This character is quite constant in all the reference collections examined (20 of P. banksiana, 20 of P. resinosa, and 11 of P. strobus), and was accordingly investigated in the fossil material.

Because the tenuitas must be clearly visible in order to make the determination, however, only a small proportion of the fossil pine grains in a routine sample can be classified to type. A given grain may be indeterminable for any of the following reasons: 1) the grain is broken into fragments (commonly only isolated bladders are encountered), 2) the tenuitas is ruptured or broken away, 3) the tenuitas is concealed by the contraction of the bladders over it, 4) the tenuitas is obscured by clinging particles of debris, 5) the exine is corroded, or 6) the grain is so oriented that the tenuitas cannot be clearly seen. The last difficulty can be readily eliminated if a fluid mounting medium is used and special thick slides are made (for

example, the cover glass can be supported by fine sand grains of uniform size); the grains may then be rotated to a more favorable orientation. The fourth and fifth reasons are related to the matrix in which the pollen is preserved and to the state of pollen preservation and cause trouble only in certain types of sediment. The third condition is relatively rare in fossil material, unless the grains are crushed by the cover glass or by debris. The first two problems are serious ones, however, because the tenuitas is the most fragile part of the pollen grain and is easily damaged. The number of identifiable pine grains in four spectra in the pine zone at Horseshoe Lake, for example, ranges from only 1 to 17 percent of the pine grains counted, and nearly all of the unidentifiable grains result from breakage.[1]

Tests of the method used to prepare the sediment for routine counting revealed that much of the breakage of conifer pollen occurred during the preparation procedure. The most serious cause of breakage is the mechanical disaggregation that is necessary to re-disperse the sediment residue each time it is transferred to a new reagent. Special techniques were therefore devised to reduce the amount of mechanical treatment. The raw sediment was dispersed by gentle boiling with 10 percent potassium hydroxide in a reflux condenser for 15 to 60 minutes; variation in boiling time did not noticeably affect the amount of breakage. The sediment was centrifuged, washed several times by gentle shaking in water, stained, and suspended in glycerin. Slides about 100 microns thick were made and scanned for pine grains. A comparison of

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[1]Single bladders of conifer pollen were consistently counted as one-half of a whole grain, and isolated grain bodies with no bladders attached were not counted.

the breakage of pine pollen in parts of the same sediment sample prepared by this method and by the standard method is given in the table below.

	Standard method	Special method
Total number of pine grains counted	603	338
Percentage of identifiable pine grains	15	51
Percentage of Pinus strobus-type in total identifiable pine grains	10	1.8
Percentage of Pinus strobus-type in total pine grains counted	1.7	0.9

The table also reveals the startling fact that the Pinus strobus-type is a higher proportion of the identifiable grains when the percentage of identifiable grains is low than when it is high. The probable explanation is that the sculptured tenuitas of P. strobus pollen is stronger and therefore less likely to rupture than the psilate tenuitas of P. banksiana and P. resinosa. The ratio of P. strobus-type to P. banksiana/resinosa-type in the identifiable pine grains is clearly not a good measure of the ratio of the two types in the total pine pollen in a sample. Thus for the sample in the above table, the ratio of P. strobus-type to total pine pollen is known only between the limits 0.9 percent and 1.8 percent (neglecting sampling error, which in this instance is larger than the limits).

The numbers of P. strobus-type and P. banksiana/resinosa-type given in the tables in the appendix must be viewed with these qualifications in mind; for the most part the percentage of undifferentiated grains is so high that the ratio of the two types has little significance. Special preparations of four samples from Horseshoe Lake and Cedar Bog Lake were counted; the results are tabulated in table 1.

Table 1. Relative frequency of Pinus strobus-type pollen in specially prepared samples

Sample number and depth	Percentage of identifiable pine grains	Percentage of P. strobus-type in total identifiable pine grains	Percentage of P. strobus-type in total pine grains counted	Total number of pine grains counted
Horseshoe Lake				
HA 157; 945 cm	51	1.8	0.9	338
Cedar Bog Lake				
D 1717; 131 cm	59	68	40	197
B 1698; 950 cm	54	37	20	193
A 1488; 1389 cm	87	1.2	1.0	200

Cupressaceae.

Juniperus/Thuja. Thuja occidentalis (2 coll.), Juniperus communis (2 coll.), J. communis var. depressa (3 coll.), J. horizontalis (2 coll.), and J. virginiana (3 coll.) are included in this type. Pollina inap or P_1, gem, subsph. Thuja pollen tends to be larger than that of the Juniperus species seen, the pore is absent or very indistinct, and the exine between the gem is psl or only finely sca. Juniperus pollen has a distinct (in J. horizontalis) to indistinct pore and a moderately sca to heavily sca (in J. communis var. depressa) exine. The size and the character of the pore can only rarely be used to distinguish fossil pollen, most of which is broken (see Bertsch, 1961), and the sculpture is variable and not wholly reliable. Both Thuja and Juniperus types were observed in the fossil material, but no attempt was made to separate them.

Sparganiaceae.

Sparganium-type. Includes Typha angustifolia.

Zosteraceae.

Potamogeton, sect. Eupotamogeton. Includes Triglochin; the separation of the pollen of these two taxa does not seem possible in our material with ordinary optics. (See Beug, 1961.)

Gramineae.

Cerealia. Separation based on characters summarized by Beug (1961). One fossil grain, which compares well with Zea mays.

The high percentages of grass pollen in the Quercus-Betula zone at Cedar Bog Lake are due to a single type. This type compares well with Zizania aquatica, but it is also similar to other taxa in our collection. No specific identification was attempted, nor was the type systematically counted.

Liliaceae (39 sp.).

Tofieldia glutinosa. Pollina C_2, ret. In T. glutinosa (1 coll.) the lumina are angular, and the muri are of even width over the reticulum. T. pusilla (1 coll.) is distinguished by muri which often fuse into irregular verrucae. All 21 fossil grains agree well with T. glutinosa.

Salicaceae.

Populus. Pollina inap, sca-ret, subsph. Ektexine often broken into irregular patches or groups of granules by rifts (see Müller-Stoll (1956), although the fragments of exine that Müller-Stoll describes are scattered on the endexine, not on the intine, since the

base layer is not destroyed by acetolysis). Granules are irregularly spaced but usually closely crowded in aggregates. Gran-D varies from ca. 0.5 μ to less than 0.1 μ, and many of the gran are close to the limit of resolution of visible-light optics. Phase-contrast optics are valuable for studying the exine structure. Gran may be pointed (microech) or rounded (microbac), and may be either isolated and distinct or partially fused together. If the tops of the gran are fused, small irregular patches of tectate exine result (especially well developed in P. balsamifera), or the partial fusion of adjacent patches may form a rough reticulum. The fusion of the gran may be so complete that columellae cannot be distinguished, and irregular ver result. Although all of these complex structures can be found on a single grain, there are clear trends of variation among the species of the genus, and this variation permits the separation of two types.

Populus tremuloides-type. Includes P. tremuloides (7 coll.), P. grandidentata (2 coll.), and P. deltoides (5 coll.). The western P. fremontii S. Wats. (3 coll.) is also of this type, as are the European P. tremula L. (1 coll.) and P. alba L. (1 coll.). Gran tend to be distinct, relatively small, and uniformly spaced in P. grandidentata but more irregular in size and distribution in P. tremuloides and P. deltoides. Gran tend to be arranged in a microret especially in P. deltoides. An attempt was made to separate further the fossil grains into types based on these characters, but the variation in our present reference material makes the separation seem inadvisable.

P. balsamifera (5 coll.). Gran fused into irregular ver or areas of tectum, usually arranged in a coarse reticulum. The tectum may bear microech. The general aspect of the sculpture is noticeably coarser than in the P. tremuloides-type.

Juglandaceae.

Juglans. Pore number may be used to separate pollen of Juglans cinerea from J. nigra with fair accuracy. In our material, J. cinerea (2 coll., 100 grains each) has a mean pore number of 6.5 with a range from 4 to 11 pores; J. nigra (2 coll., 100 grains each) has a mean pore number of 14.4 with a range from 10 to 20 pores. Data published by Whitehead (1963) confirm the distinction: of a sample of 100 grains each of 44 collections of J. cinerea, the modal class he reported was 8 pores and the range 2 to 15 pores, whereas 42 collections of J. nigra had a modal class of 17 and a range of 9 to 37 pores. In my fossil material, grains with fewer than 10 pores were assigned to J. cf. cinerea and grains with more than 10 pores are designated J. cf. nigra. Whitehead's comprehensive data indicate that a division at 11 pores is more accurate, and that the number of fossil grains in the range of overlap (9 to 15 pores) should be recorded; this was not done in the present study.

Corylaceae.

Ostrya/Carpinus. The pollen of Ostrya virginiana (5 coll.) cannot be distinguished from that of Carpinus caroliniana (5 coll.). Grains in both species are predominantly P_3, as were the fossil grains counted.

Betula. No attempt was made to separate the pollen of Betula species. Betula papyrifera, B. lutea, B. pumila, and possibly B. glandulosa and B. nigra may all have contributed pollen to the sediments studied.

Alnus. The only species of Alnus likely to occur in the fossil material studied are A. rugosa (var. americana) and A. crispa. These species differ in pore-number frequency (Davis, 1954), with the

former being predominantly P_4 and the latter predominantly P_5. In addition, there are important differences in the pore structure. In A. rugosa var. americana (4 coll.) the arci and annuli are strongly developed; the pore is usually vestibulate, with the thickened ektexine slightly separated from the endexine at the pore; the pore in the ektexine (exopore) is meridionally elongated, and the pore beneath it in the endexine (endopore) is isodiametric and has a diameter equal to or greater than the meridional diameter of the exopore. In A. crispa (4 coll.) the arci and annuli are weakly developed; the pore is not vestibulate; the exopore is meridionally elongated, but the endopore is usually elongated equatorially, and its meridional diameter is less than the meridional diameter of the exopore.

The fossil grains agreed well with Alnus rugosa var. americana.

Ulmaceae.

Celtis occidentalis (2 coll.). Pollina P_3, tec, psi; col-D,+ 0.7μ, col inord; media. Annulus prominent, formed by the complete fusion of tectum and endexine; slight cost P.

Moraceae.

Morus rubra (3 coll.). Pollina P_2 (rarely P_3), op, intec, sca (microver); minuta, subsph. Annulus faint, slight cost P.

Cannabinaceae.

Humulus lupulus (3 coll.). Pollina P_3, intec, sca, minuta-media, subsph. Annulus distinct, formed by the inward protrusion of the ektexine around the pore.

cf. Cannabis sativa. The presence of Cannabis sativa, an introduced weed, must be considered in surface pollen spectra. Its

pollen is very similar to that of Humulus lupulus. In our material, the pore structure of Cannabis (1 coll.) differs slightly from that of Humulus, with the ektexine not so distinctly separated from the endexine in the annulus; the annulus in Cannabis is thus thinner than in Humulus. Three fossil grains in near-surface spectra (Cedar Bog Lake) agree well in this respect with Cannabis.

Urticaceae.

Urtica-type. Pollina P_3, intec, sca (gran inord); ex-M,+ < 1 μ; minuta, subsph. Pores protrude slightly, with thin cost P. Includes Urtica gracilis (3 coll.), U. procera (1 coll.), U. viridis (1 coll.), Boehmeria cylindrica (in part) (2 coll.), and Parietaria pensylvanica (in part) (2 coll.). Boehmeria cylindrica is predominantly P_2, but a few grains may be P_3 and may then be indistinguishable from Urtica. Similarly, triporate grains may occur in Parietaria pensylvanica, which is normally stephanoporate.

Laportea-type. Pollina P_2, intec, sca (gran inord); ex-M,+ < 1 μ; perminuta-minuta, subsph. Gran-D,+ 0.5 μ. Includes Laportea canadensis (2 coll.) and Boehmeria cylindrica (in part; see above).

Pilea-type. Pollina P_2, intec, sca (microver, inord), ex-M,+ ≥ 1 μ, minuta, subsph. Gran-D,+ 1.0 μ, gran (microver) widely spaced compared with Laportea. Includes Pilea pumila (2 coll.), P. fontana (1 coll.), and possibly a few grains (not more than 10 percent) of Laportea canadensis that have a relatively coarse sculpture.

Polygonaceae.

Rumex. The following native North American species were studied: Rumex verticillatus (1 coll.), R. mexicanus (1 coll.), R. altissimus (1 coll.), R. fenestratus (1 coll.), R. orbiculatus (1 coll.), R. maritimus var. fueginus (4 coll.), and R. graminifolius

(1 coll.); other species are unlikely to have occurred near the sites before the introduction of European species. The morphology of the pollen of these species in our material is summarized in the table below (p. 30); Oxyria digyna (1 coll.) has similar pollen and is included for comparison.

Seven fossil grains agreed closely with Rumex mexicanus and one matched R. maritimus var. fueginus well. Because of the limited number of reference collections studied, however, it seems best to keep the identifications tentative until more is known of the variation within the genus.

Polygonum amphibium-type. Pollina C peri, ret. Includes P. amphibium var. stipulaceum (4 coll.) and P. coccineum (1 coll.). Four fossil grains, which agree very well with P. amphibium var. stipulaceum.

Polygonum lapathifolium-type. Pollina P peri, ret. Includes P. pensylvanicum, P. lapathifolium, P. careyi, P. hydropiper, P. punctatum, P. hydropiperoides, P. sagittatum, and P. arifolium (1 coll. each). One fossil grain.

Chenopodiaceae-Amaranthaceae (55 sp., 65 coll.).

Chenopodium-type. Includes species of Atriplex, Chenopodium, Corispermum, Cycloloma, Eurotia, Monolepsis, Salicornia, and Suaeda in in the Chenopodiaceae, and Acnida and Amaranthus in the Amaranthaceae. No attempt was made to subdivide this rather heterogeneous group.

Salsola kali (3 coll.). Pollina P peri; Pβ 2, Pγ 2; tec, col-D ca. 0.5μ; sca (microech); minuta-media. Five fossil grains.

Sarcobatus vermiculatus (4 coll.). Pollina P peri (PΣ 10-15); Pβ 3a, Pγ 1-Pγ 2; tec, col-D $<$ 0.5μ; psi; minuta. The raised annulus,

Species	Type	Pore structure	Sculpture and structure	Shape of lum or perf	Polar-I	Size
Rumex verticillatus	C_3P_3	Pαb-Pαa; Pα1 (cost P thin)	psi, tec perf; col incertae-distinct; col-D,+ < 0.5μ; perf-D = col-D	isodiametric, rounded	small-medium	medium
R. mexicanus	C_3P_3	Pαa; Pα2 (cost P moderate)	ret, intec (some grains psi, tec perf); col incertae-distinct; col-D,+ < 0.5μ; lum (perf)-D > col-D	irregular, angular	medium-large	small
R. altissimus	C_3P_3	Pαa; Pα4 (cost P thick)	ret, intec; col distinct; col-D,+ < 0.5μ; lum-D = col-D	isodiametric, rounded	medium	small-medium
R. maritimus var. fueginus	C_3P_3	Pαa; Pα2 (cost P moderate)	ret, intec; col distinct; col-D,+ > 0.5 ; col-D ≥ lum-D	isodiametric, rounded	small-medium	small-medium
R. fenestratus	CPperi	Pαa; Pα2-Pα4 (cost P moderate)	sca, tec perf; col distinct; col-D,+ < 0.5μ; perf-D ≤ col-D	isodiametric, rounded		medium
R. orbiculatus	CPperi	Pαb-Pαa; Pα2-Pα4 (cost P thick)	ret, intec; col distinct; col-D,+ ≤ 0.5μ; lum-D = col-D	isodiametric, rounded		medium
R. gramineus	CPperi	Pαb-Pαc; Pα2 (cost P moderate)	ret, intec-sca, tec perf; col incertae-distinct; col-D,+ < 0.5μ; lum-D > col-D	irregular, angular		small-medium
Oxyria digyna	C_3P_3	Pαa-Pαb; Pα2 (cost P moderate)	sca-psi, tec perf; col distinct; col-D,+ > 0.5 μ; perf-D = col-D	isodiametric, rounded	medium	small

formed by the lengthening of the col around the pore, is a distinctive feature of this grain. Fossil grains frequent but scattered.

Ranunculaceae (49 sp., 66 coll.).

Ranunculus-type. Includes species of Ranunculus, Myosurus, Hepatica, and Clematis. Further separation of this group must await more complete reference material. Four fossil grains.

Caltha-type. Includes species of Caltha and Aquilegia. One fossil grain.

Thalictrum. The following species were possible contributors to the pollen rain: T. alpinum (2 coll.), T. dioicum (1 coll.), T. confine (1 coll.), T. venulosum (1 coll.), and T. dasycarpum (5 coll.). The table below summarizes the differences in pollen morphology of these species, together with the similar species Anemonella thalictroides.

Species	Pore delimitation	Arrangement of col	Sculpture	Spacing of microech
Thalictrum alpinum	Pβ 2	intrabac, ord	microech distinct	moderate
T. dioicum	Pβ 2	intrarot, inord	microech faint-distinct	moderate
T. confine	Pβ 2-Pβ 1a	col incertae-intrabac, ord	microech distinct	close
T. venulosum	Pβ 1a	col incertae-intrabac, ord	microech distinct	close
T. dasycarpum	Pβ 2	intrabac, ord-col incertae	microech absent-faint	close
Anemonella thalictroides	Pβ 2	intrabac, inord	microech faint	wide

Fossil grains at Horseshoe Lake were separated into types based on these characters. One grain was referred to T. dioicum, ten grains to T. confine-type (includes T. confine and T. venulosum), and 22 grains to T. dasycarpum.

Cruciferae (66 sp.).

cf. Brassica. Pollina C_3, ret; grain larger and ret coarser than in most genera of Cruciferae. Three fossil grains from recent spectra agree well with Brassica kaber (2 coll.); other Brassica species not seen. Also similar: Cardamine (2 coll.), Dentaria (1 coll.); not all native species of these genera were seen.

Saxifragaceae (45 sp., 51 coll.).

cf. Penthorum sedoides (1 coll.). Pollina C_3P_3, Cα3a; polar-I < 0.19; intec, ex-I 0.10-0.20; psi-rug; minuta, subsph. Similar grains are found in Heuchera parvifolia Nutt. (1 coll.), but this western species is not likely to have occurred in Minnesota. The grains of other species seen are different. One fossil grain.

cf. Heuchera richardsonii (2 coll.). Pollina C_3P_3, Cα3c, Pαa; ret, lum < 1μ; minuta, subprol. Similar grains are found in: Mitella nuda (1 coll.; coarser ret, tendency for tec pol), Saxifraga pensylvanica (2 coll.; Cα3d-Cα4, coarser ret), Veronicastrum virginicum (1 coll.; Cα3a, lum angular), Linaria canadensis (1 coll.; larger pol-M, coarser ret), and Bartonia virginica (1 coll.; P distinct, coarser ret). One fossil grain.

Leguminosae (104 sp.).

Amorpha. Pollina C_3P_3, Cγ3, intec, ret, subsph. Operculi frequently lost in fossil grains. Includes A. canescens (2 coll.), A. fruticosa (1 coll.), and A. nana (2 coll.). Twelve fossil grains.

Petalostemum purpureum (2 coll.). C_3, Cγ3, intec, ret, prol. Lg/Lt > 1.60, Lg > 35 μ. Ret is heterobrochate, with small lum (lum-D ca. 0.1 μ) scattered between the larger lum (lum-D,+ 1.5 μ). Lum-D decreases at pol and inter C,med. Col easily resolvable (col-D,+ 0.2 μ). Op-Lt,+ 2.5 μ. Dalea has grains of similar shape and size, but ret is homobrochate, lum smaller (lum-D,+ 0.8 μ in Dalea alopecuroides (1 coll.); D. enneandra (1 coll.) is better described as tec, psi), and op-Lt,+ larger (ca. 4.3 μ). Two fossil grains.

Petalostemum candidum-type. Includes P. candidum (1 coll.) and P. villosum (2 coll.). Differs from P. purpureum as follows: Lg/Lt < 1.60 (< 1.40 in P. candidum), Lg < 30 μ. Ret is homobrochate; lum-D,+ ca. 1.2 μ; lum-D fairly constant over grain (except for mg). Col incertae or < 0.1 μ. P. occidentale (1 coll., Lg/Lt > 1.60) and P. multiflorum (1 coll.) are similar. Sixteen fossil grains.

Hedysarum (3 sp., 4 coll.). Pollina C_3, Cγ2; intec, ret; minuta, prol. Two fossil grains.

Prosopis cf. pubescens. Pollina C_3P_3, Cβ1a, Pαa; fov; media, subsph. Prosopis has a distinctive grain that is unlike any other type seen. One fossil grain agrees well with P. pubescens (2 coll.), less well with other Prosopis species seen (5 sp., 7 coll.).

Rutaceae.

Xanthoxylum americanum (2 coll.). Pollina C_3P_3; Pαc-trC, Cβ3a; cost tr; polar-M < 0.25; intec; ret-str, heterobro, col incertae; minuta, subprol. Ptelea trifoliata (1 coll.) is similar, but has a longer trC and is less striate. Four fossil grains.

Euphorbiaceae.

Euphorbia sub-gen. Chamaesyce (4 sp., 4 coll.). Pollina C_3P_3,

Cβ3b, Pαc-trC; intec, ret, col(simpl); minuta-media, subsph. Six fossil grains.

Anacardiaceae.

Rhus. Pollina C_3P_3; trC, cost tr; intec, str-ret. The longer trC, apiculate shape in equatorial view, and usually distinct col serve to distinguish the pollen from that of Xanthoxylum. In our material, the sculpture differs among the species; Rhus glabra (2 coll.) and R. typhina (1 coll.) have coarse muri and col, R. radicans (2 coll.) is ret-str with small col, and R. vernix (2 coll.) is finely str-ret with small col. One fossil grain agreed well with R. radicans and one with R. vernix.

Aceraceae.

Acer spicatum (3 coll.). Pollina C_3P_3; tec, col-D,+ $< 0.5\mu$; str; minuta, subsph-prol.

Acer saccharum (8 coll.; includes A. nigrum). Pollina C_3; intec, str-ret, col-D,+ $> 0.5\mu$; media-magna, subsph-prol. Sculpture is sometimes ret with the muri having no consistent direction, but more often the muri (= vallae) are sub-parallel and anastomose to inclose lumina. The height (altitude) of the vallae is constant, and in optical section the surface of the ektexine appears smooth.

Acer rubrum (4 coll.). Pollina C_3; tec?, col-D,+ $< 0.5\mu$; str; media, subsph. Val do not inclose lumina.

Acer negundo (6 coll.). Pollina C_3, intec; rug-ret, col-D,+ $< 0.5\mu$; minuta-media, subsph. Val tend to be irregular in width and height; when they inclose lumina the lum are irregular, and in optical section the exine surface often appears rough.

Acer saccharinum-type. Pollina C_3; tec; col-D,+ < 0.5 μ; psi-rug; media, subsph. Includes Acer saccharinum (4 coll.) and possibly a few A. negundo, from the bulk of which it differs in its appreciably finer sculpture.

Haloragaceae (9 sp., 12 coll.).

Myriophyllum exalbescens-type. Pollina P stp, PΣ 3-5, Pα b-Pα a, Pβ 3; psi-fov-sca; media, obl. Includes Myriophyllum exalbescens (3 coll.) and M. tenellum (1 coll.).

Umbelliferae (73 sp., 80 coll.).

cf. Sium suave. Pollina C_3P_3, trC, tec, psi, minuta-media, prol. Pollen of this species is distinguished from other Umbelliferae by its smooth elliptical shape, elongated elliptical trC, and cost tr that often form an internal vestibulum. (See Ting, 1961.) One fossil grain.

Ericaceae-type.

Includes members of the Ericaceae, plus Moneses uniflora, Pyrola virens, P. elliptica, P. rotundifolia, and P. asarifolia of the Pyrolaceae. No distinctions within this heterogeneous group were made.

Oleaceae.

Fraxinus pennsylvanica-type. Pollina C stp-C_3, Cα3f; intec; ret; minuta, subsph. Colpus margin irregular, poorly defined. Normally C stp (CΣ 4). Includes F. pennsylvanica and vars. (7 coll.) and F. americana (2 coll.).

Fraxinus nigra-type. Pollina C_3-C peri, Cα2a-Cα3c; intec; ret; minuta, subsph. Colpus margin well defined, often straight. Normally C_3; if CΣ>3, then C peri. Includes F. nigra (2 coll.) and F. quadrangulata (1 coll.); the latter species is unlikely to have

contributed much pollen to Minnesota sediments. Colpi tend to be longer than in F. pennsylvanica. The reticulum tends to be coarser and the columellae larger in F. nigra than in F. pennsylvanica, but this character cannot be used alone to separate the two types.

Polemoniaceae.

Phlox pilosa-type. Pollina P peri, ret, media (M,+ < 35 μ), subsph. Includes Phlox pilosa var. fulgida (2 coll.) and P. divaricata var. laphamii (1 coll.). P. maculata (1 coll.) has larger grains (M,+ > 40 μ) and tends to have low muri within the lumina of the prominent reticulum, whereas the P. pilosa-type has psi lum. Polygonum (sections Persicaria and Echinocaulon) differs in having large col within the lumina of the ret.

Hydrophyllaceae.

Hydrophyllum cf. virginianum. Pollina C syn, C γ 2; tec, psi; minuta, subsph. Two fossil grains agree very well with H. virginianum (1 coll.), less well with H. appendiculatum (1 coll.).

Phacelia cf. franklinii. Pollina C_3, C γ 2, ret, minuta, subsph. Ret coarser in inter C,med; inter C,med is depressed to give grain hexagonal shape in polar view. One fossil grain agrees very well with P. franklinii (1 coll.); other species are unlikely to have occurred.

Boraginaceae.

Onosmodium (1 coll.). Pollina CP stp, P Σ 8; sca; heteropol, minuta, subsph. Two fossil grains.

cf. Mertensia paniculata (2 coll.). Pollina C het, C Σ 6, P Σ 3, C-Lg = CP-Lg, P-Lt $\geq$ C-Lt,+; psi; minuta-perminuta, prol. Similar grains are found in Mertensia maritima (1 coll.; grain smaller and

less constricted, P-Lt = C-Lt,+), M. virginica (1 coll.), Myosotis verna (1 coll.; C-Lg ≥ CP-Lg; grain smaller, less prol, less constricted), and M. laxa (1 coll.; C-Lg > CP-Lg, P-Lt > C-Lt,+). Five fossil grains all agree well with Mertensia paniculata.

Labiatae.

Scutellaria cf. epilobiifolia. Pollina C_3, $C\beta 3a$; tec, col incertae; ret; minuta, subsph. Lum-D decreases at pol. One fossil grain agrees well with S. epilobiifolia (1 coll.), not with other species seen (4 sp., 4 coll.).

Lycopus-type. Pollina C stp, $C\Sigma 6$, intec, ret, media, subsph. Includes pollen of Monarda (3 coll.), Hedeoma (1 coll.), Satureja (2 coll.), Pycnanthemum (1 coll.), Lycopus (5 coll.), Mentha (3 coll.).

Dracocephalum-type. Pollina C stp, $C\Sigma 6$, tec, intrabac; ret; media, subsph. Includes pollen of Agastache (2 coll.), Dracocephalum (1 coll.), and Prunella (1 coll.).

Plantaginaceae.

Plantago. The following native species of Plantago were possible contributors to the pollen rain: P. cordata (1 coll.), P. major (var. pilgeri) (4 coll.), P. rugelii (2 coll.), P. eriopoda (1 coll.), P. oliganthos (1 coll.), P. aristata (1 coll.), P. spinulosa (1 coll.), P. purshii (1 coll.), and P. pusilla (1 coll.). Littorella americana (2 coll.) has similar pollen. All are P peri, $P\gamma 2$. The table below (p. 38) summarizes the important distinctions of pollen morphology of these species as seen in our limited material. (See also Andersen, 1961.) One fossil grain was referred to P. major and one to P. rugelii.

Type	Pore delimitation	Verrucae	Scabrate elements	Columellae
Plantago oliganthos	Pβ3a	distinct-indistinct	distinct	absent-indistinct
P. pusilla	Pβ2	distinct	distinct, minute	absent-indistinct
P. rugelii	Pβ1a	absent	distinct	absent-indistinct
P. spinulosa	Pβ1a	distinct	distinct	distinct
P. purshii, P. aristata, P. cordata	Pβ1a	distinct	distinct	absent-indistinct
P. eriopoda, Littorella americana	Pβ1a	distinct	absent; fov	absent-indistinct
P. major	Pβ1a	distinct	absent; psi	absent-indistinct

Caprifoliaceae.

Viburnum lentago (2 coll.). Pollina P_3C_3, Cα3a, trC; intec; ret-cla; minuta, subsph. The sculpture elements of this grain may be isolated (thin cla or bac) or joined at the extreme top to form a ret; this feature distinguishes the species from other Viburnum species seen. One fossil grain.

Viburnum trilobum (2 coll.). Pollina P_3C_3, Pαb-trC, Pα4; intec; ret, simplibac; minuta, subsph. The pollen of this species differs from that of other Viburnum species seen in its pore, which is less elongated equatorially, and in the cost P (cost tr), which tend to form an internal pore vestibulum. One fossil grain.

Compositae.

Iva ciliata-type. Pollina C_3P_3, Cβ2b, polar-I very large; tec; col-D,+ > 1.0μ; ech; minuta, subsph. The coarse columellae of

this pollen type distinguish it from all other Ambrosieae. In our material the type includes Iva ciliata (3 coll.), I. frutescens (1 coll.), I. imbricata (1 coll.), I. angustifolia Nutt. (1 coll.), and I. microcephala Nutt. (1 coll.).

Iva xanthifolia-type. Pollina C_3P_3, Cβ2a, polar-I medium; tec; col-D,+ < 0.5μ; ech; minuta, subsph. This type resembles Ambrosia-type except for its long colpi. Includes Iva xanthifolia (3 coll.) and I. dealbata Gray (2 coll.).

Ambrosia-type. Pollina C_3P_3, Cβ2b, polar-I very large; tec; col-D,+ < 0.5μ; ech; minuta, subsph. In our material the type includes species of Ambrosia (8 sp., 17 coll.) and Franseria (8 sp., 11 coll.), and Iva axillaris Pursh (2 coll.).

Unidentified types

Unknown.

The unknown category comprises those grains that are preserved well enough to permit recognition of their essential features but that cannot be assigned with confidence to any taxon below the rank of order. Each can be classified as a distinct type that can be identified when it occurs again. Many of the unknown types are of course derived from taxa whose pollen is unfamiliar to me, but some may represent immature or teratological grains of familiar taxa. The table below summarizes the occurrence of unknowns at the three sites described.

Site	Number of unknown grains	Number of unknown types
Cedar Bog Lake	17	15
Horseshoe Lake	23	23
Andree Bog	33	29
Total of three sites	73	65

Indeterminable.

The indeterminable category comprises grains whose essential features are in some way so obscured that the grains cannot be assigned with confidence to any pollen type, known or unknown. Unlike the grains classed as unknown, indeterminable grains cannot be differentiated into distinct pollen or spore types. Grains may be indeterminable for various reasons, and they may be grouped into smaller categories accordingly.

Indeterminable: deteriorated. These are pollen grains and spores whose exine has undergone a change so great that the essential characteristics of structure and sculpture cannot be recognized. At least two distinct conditions are observable in such damaged exines. The exine may show a peculiar pitting or etching, much as if a part of it (commonly the ektexine) had been gnawed away. Grains exhibiting this condition are here called corroded. The corrosion must normally be severe, with most of the exine destroyed, before the grain becomes indeterminable. On the other hand, the damage to the exine may appear to result from a rearrangement of the pollen-wall substance, without any noticeable subtraction of material. Structural and sculptural elements can no longer be resolved, and the pollen wall becomes essentially amorphous. Grains affected by this condition are here called degraded. The entire exine of a grain is normally affected by the condition, and most such grains are indeterminable. Often when the degraded condition is severe (as in the lower spectra at Andree Bog) it becomes difficult to distinguish pollen grains and spores from other organic particles, and counting becomes highly subjective.

Indeterminable: broken/concealed. Grains that are so broken or fragmented that they cannot be recognized are included in this

category, as are those that are too crushed or crumpled to be recognizable, even though the exine may not be ruptured. Also included are grains whose features are obscured by organic or mineral particles that surround or adhere to them. A very few grains may be included because for some reason they cannot be turned to an orientation favorable for study.

POLLEN STRATIGRAPHY AND VEGETATION HISTORY AT CEDAR BOG LAKE

Cedar Bog Lake lies within the Cedar Creek Natural History Area in northern Anoka and southern Isanti Counties, Minnesota. The geologic setting of the area has been well known since the work of Cooper (1935), and various aspects of the environment and biota of the area have been studied since then. Among the studies of particular interest here are those of the limnology and the developmental history of Cedar Bog Lake and the bog that surrounds it (Lindeman, 1941a, 1941b, 1942), the fluctuations of the surface of the bog (Buell and Buell, 1941), the pollen stratigraphy (Artist, 1939; Lindeman, in Flint and Deevey, 1951), the stratigraphic distribution of lipoid substances and amino acids in the bog (Swain and Prokopovich, 1954; Swain, Blumentals, and Millers, 1959), the bog vegetation (Conway, 1949), and the upland vegetation (Chu, 1948). A checklist of the flora of the area has been published by Moore (1952), and a description of the vegetation cover types of the entire area, together with a summary of the land-use history, is provided by Pierce (1954).

The attractiveness of the site for studies of vegetation history is increased by the peculiar combination of plants for which it is known. The well-developed stand of Thuja occidentalis (northern white-cedar) that gives the area its name is at the southern limit of distribution of this species, and other conifer species important in the northern forests occur there as well. Two other plants that are common in the area, Decodon verticillatus (water-willow) and Rhus vernix (poison-sumac), are at or near their northern limit of range there. The area, in fact, lies within the tension zone between northern

and southern floristic provinces defined by Curtis (1959) in Wisconsin, if that zone is extended west into Minnesota. Furthermore, small stands of Acer saccharum (sugar maple) plus Tilia americana (American basswood), a community that is rare on the Anoka Sand Plain as a whole, occur within the Area. The presence of these distinctive species together in the Cedar Creek area poses questions whose solution pollen analysis can aid. The existence of a rich flora, moreover, in itself promises a wealth of information as the record of that flora is traced back in time.

Location and description of site

Cedar Bog Lake is in the NW¼ sec. 27, T. 34 N., R. 23 W., Anoka County, Minnesota, on the extensive body of outwash known as the Anoka Sand Plain (fig. 1). The lake lies within an extensive area of bog forest and is evidently the remnant of a larger body of water. This inference was confirmed by Lindeman (1941a), who made a series of borings along a northwest-southeast transect across the bog and lake. With the resulting data he constructed a cross-section and showed that lake sediments extended beneath a surface layer of peat.

Borings for the present study were made very near the site of Lindeman's profile station 2, at the center of the north end of the lake (fig. 2). Lindeman was unable to penetrate the entire thickness of sediment at this station, and his section (1941a, fig. 1) shows the inferred base of the organic sediments at 12 meters below the surface level. The core taken for the present study reached the bottom of the organic sediments at 16.6 meters below water level. Some uncertainty exists in comparing this depth with Lindeman's figures, because of fluctuations in the reference surface levels (Buell and Buell, 1941);

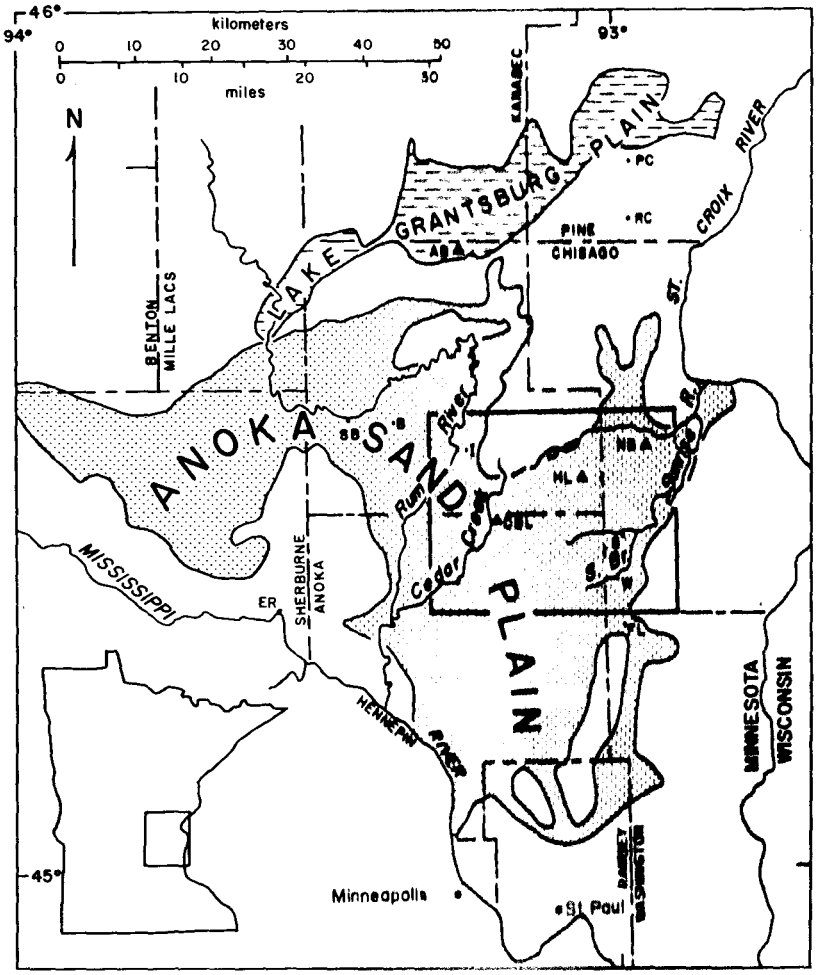
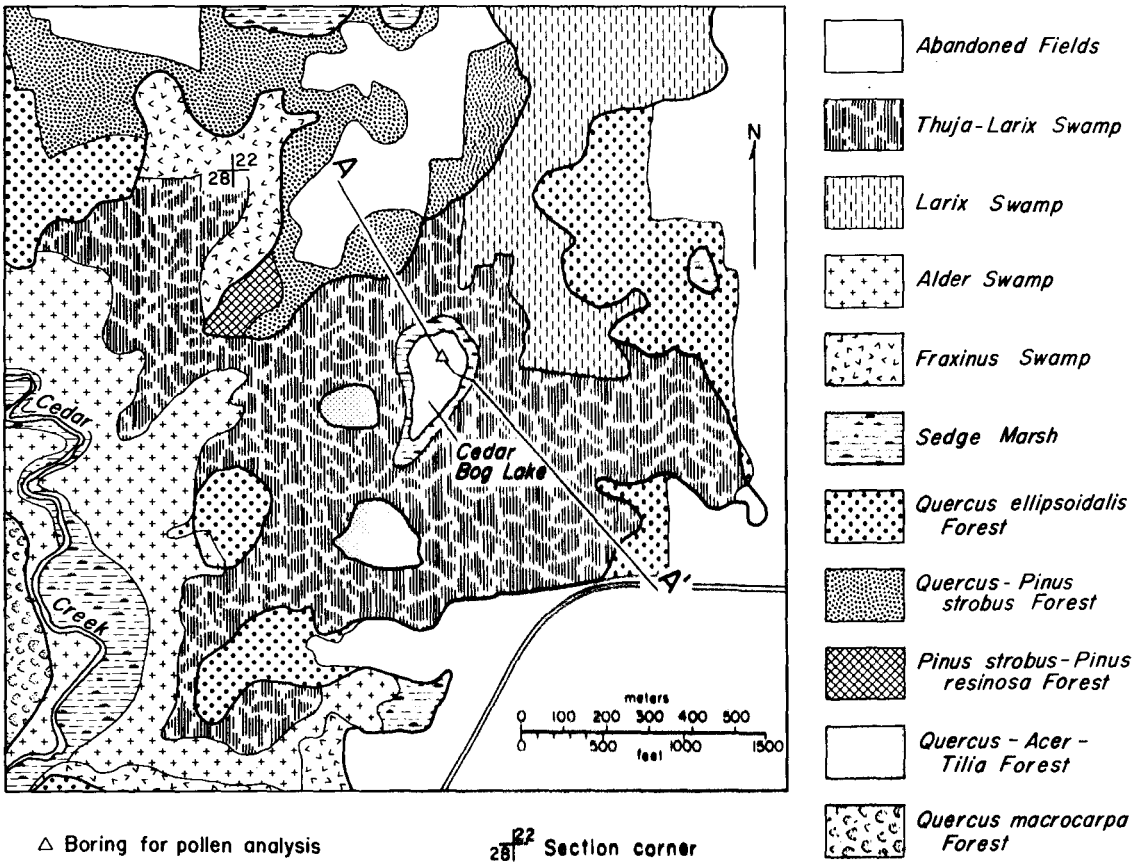


Figure 1. Index map of east-central Minnesota, showing locations mentioned in the text. Triangles indicate sites of pollen diagrams: AB = Andree Bog, CBL = Cedar Bog Lake, HL = Horseshoe Lake, NB = North Branch buried peat. Dots indicate places: B = Bradford, ER = Elk River, FL = Forest Lake, I = Isanti, PC = Pine City, RC = Rock Creek, S = Stacy, SB = Spencer Brook, W = Wyoming. Heavy outline is map area of Figures 13 to 15. Area of index map is shown on the inset map of Minnesota.



F i g u r e 2 . Vegetation map of Cedar Bog Lake area, Anoka and Isanti Counties. Vegetation types generalized after Pierce. Heavy line separates upland and lowland, as shown on preliminary topographic map prepared by Mark Hurd Aerial Surveys, Inc. A - A': line of cross-section, figure 5.

the difference, however, is unlikely to be more than one meter. The cross-section in figure 5a is a modification of Lindeman's profile. The surface profile is taken from a preliminary topographic map of the Cedar Creek Natural History Area (scale 1:4800) made by Mark Hurd Aerial Surveys Inc., and the subsurface data are Lindeman's, except that the new boring in the center of the lake is substituted for his profile station 2.

The dominant tree on the uplands surrounding Cedar Bog Lake, as on the Anoka Sand Plain as a whole, is Quercus ellipsoidalis (northern pin oak). This species may occur as nearly pure stands with an open canopy or as a dominant or sub-dominant associated with one or more of the following trees: Quercus alba (white oak), Quercus macrocarpa (bur oak), Quercus rubra var. borealis (northern red oak), Betula papyrifera (paper birch), Pinus strobus (eastern white pine), Pinus resinosa (red pine), and Pinus banksiana (jack pine). Understory shrubs include Corylus americana (American hazel), Vaccinium angustifolium (blueberry), and Ceanothus americana (New Jersey tea).

Two isolated knolls or "islands" surrounded by Thuja-Larix swamp lie to the south and west of Cedar Bog Lake (fig. 2) and support stands of Quercus rubra var. borealis with Acer saccharum and Tilia americana and an occasional large Pinus strobus. Ostrya virginiana (eastern hophornbeam), Quercus alba, Quercus ellipsoidalis, Betula papyrifera, and Acer rubrum (red maple) are sub-dominants, and Corylus cornuta (beaked hazel), Rhus glabra (smooth sumac), and Celastrus scandens (bittersweet) occur in the understory.

The swamp forest is dominated by Thuja occidentalis and Larix laricina (tamarack). Thuja tends to be concentrated near the uplands, where it may form dense mature stands with little understory

growth, but Larix is more frequent farther from the uplands in more open stands with an often dense undergrowth. Betula papyrifera, Pinus strobus, and an occasional Picea mariana (black spruce) may share the canopy locally, and close to the uplands Fraxinus nigra (black ash), Ulmus americana (American elm), Betula lutea (yellow birch), Acer rubrum, Prunus serotina (black cherry), Betula papyrifera, Populus tremuloides (quaking aspen), and Populus grandidentata (bigtooth aspen) may become common enough to form a distinct but narrow hardwood community. Shrubs in the swamp forest include Rhus vernix, Cornus stolonifera (red osier), Betula pumila var. glandulifera (swamp birch), Salix species (willow), Corylus cornuta, Ledum groenlandicum (labrador-tea), Chamaedaphne calyculata (leather-leaf), and Alnus rugosa var. americana (speckled alder); the last species locally dominates the vegetation. Sphagnum is present throughout much of the swamp forest.

A narrow sedge mat surrounds Cedar Bog Lake. Carex lasiocarpa (sedge) is the dominant plant. Decodon verticillatus fringes the lake edge, and Typha latifolia (cat-tail) and Phragmites communis (reed) occur in scattered patches on the mat.

In the lake itself, Ceratophyllum demersum (hornwort), Najas flexilis (naiad), and Potamogeton species (pondweed) are abundant. Lindeman (1942b) gives an extensive description of the biota of the lake.

Sediment stratigraphy

The sediments underlying Cedar Creek Bog and Cedar Bog Lake have been described by Lindeman (1941a) and Swain and Prokopovich (1954), and the present study adds little to their descriptions. Yet a wealth of unexplored information is contained in the sediment, and

detailed lithologic and paleontologic investigations would prove highly fruitful in the attempt to reconstruct past environments. The pollen analysis presented here must be considered only a small part of the larger search.

A description of the core used for pollen analysis follows; depths given are from the water level at the time of sampling.

0 - 130 cm: Open water.

130 - 288 cm: Fine-detritus copropel ("ävja-gyttja" of Lindeman). Ld^0 2, Dg 2; dark olive-gray, very soft, calc 0. Najas seeds abundant. Microscopic estimate: fine silt and clay rare (common in surface sample), pyrite very rare, cellular fragments common (Ceratophyllum spines rare), hyphae very rare, pollen infrequent, algae abundant (diatoms in surface sample, cf. Gloeotrichia below), chitin infrequent, charcoal rare. Lower contact gradational.

288 - 403 cm: Fine-detritus marly copropel. Ld^0 2, Dg 2, [test. (moll.) +]; medium olive-gray, very soft, calc 0; grading downward to Ld^0 2, Dg 1, Lc 1, [test. (moll.) +]; light olive-gray, calc 3. Najas seeds abundant to 360 cm, less common below. Microscopic estimate: as above. Lower contact sharp.

403 - 592 cm: Copropelic marl ("marl" of Lindeman). Lc 3, Ld^0 1, [test. (moll.) 1]; light to medium gray, soft, calc 4. Najas seeds rare, except common 450-460 cm. Microscopic estimate: fine silt and clay infrequent, pyrite very rare, cellular fragments infrequent, hyphae very rare, pollen infrequent, algae common (Pediastrum, Tetraedron, Botryococcus, others), chitin infrequent, charcoal infrequent. Lower contact gradational.

592 - 930 cm: Marly copropel. Ld^0 2, Lc 2, [test. (moll.) +]; medium olive-gray, soft, calc 3. Najas seeds infrequent. Test. (moll.) 2 at 685-695 cm. Vivianite rare

in scattered masses. Laminae of light olive granular marl rare. Microscopic estimate: fine silt and clay infrequent, pyrite very rare, cellular fragments infrequent, hyphae very rare, pollen rare, algae common (diatoms, chrysophyte statospores), chitin rare, charcoal infrequent. Grades below 860 cm to unit below.

930 - 1000 cm: Marly humified copropel ("dark gyttja" of Lindeman). Ld^3 3, Lc 1, Dh +; very dark gray, firm, calc 3. Vivianite rare. Microscopic estimate: medium to coarse silt common, pyrite very rare, cellular fragments abundant, hyphae infrequent, pollen rare, algae infrequent (chrysophyte statospores, diatoms, cf. Cyanophyceae), chitin very rare to infrequent, charcoal common. Grades below 990 cm to unit below.

1000 - 1350 cm: Marly copropel ("marl" of Lindeman). Ld^0 2, Lc 2; medium olive-gray, firm, calc 3. Microscopic estimate: fine silt and clay infrequent, pyrite very rare, cellular fragments common, hyphae very rare, pollen common, algae common (Tetraedron, Pediastrum, cf. Gloeotrichia, diatoms), chitin very rare, charcoal rare to infrequent. Lower contact gradational.

1350 - 1620 cm: Sideritic marly copropel ("gyttja" of Lindeman). Ld^0 2, Lc 1, Lf 1; medium olive-gray, very firm, calc 3. Changes color quickly on exposure to air to very dark gray, and after longer exposure to medium yellow-brown. Vivianite rare. Laminae of very dark gray infrequent. Microscopic estimate: fine silt and clay infrequent, pyrite very rare, cellular fragments infrequent, hyphae very rare, pollen infrequent, algae common (Pediastrum, Tetraedron, Scenedesmus, others), chitin very rare, charcoal rare. Lower contact gradational.

1620 - 1660 cm: Sideritic copropel. Ld^0 2, Lf 2, Ga +; very dark gray, very firm, calc 2. Vivianite rare. Microscopic estimate (after HF treatment): pyrite abundant

to very rare,[2] cellular fragments common, hyphae very rare, pollen common, algae rare (Pediastrum, Botryococcus), chitin very rare, charcoal rare. Lower contact gradational over 2 mm.

1660 - 1662.5 cm: Coarse-detritus copropel. Ld^2 2, Dg 1, Dl 1, Dh +, Ga +; very dark gray, very firm, calc 0. Microscopic estimate (after HF treatment): pyrite not seen, cellular fragments very abundant, hyphae common, pollen infrequent, algae not seen, chitin very rare, charcoal rare. Lower contact sharp.

1662.5-1690+ cm: Medium sand. Ga 4; medium gray, calc 0.

Pollen zones

The sediments of Cedar Bog Lake are divided into four pollen zones and seven named subzones on the evidence of the pollen and spore assemblages shown in the diagram, figure 3. The zones are believed to have regional significance, but the subzones are more likely to reflect local environmental changes and may not be traceable beyond the Cedar Bog Lake basin. The zones and subzones are indicated on the pollen diagram, figures 3 and 4, and are defined below from the bottom up.

Picea-Larix assemblage zone.

Picea dominates this zone, which is the lowest zone recorded in the sediments of Cedar Bog Lake, and Larix is constantly present. Non-arboreal pollen occurs in moderate quantities, and a variety of other trees are well represented, including Betula, Populus, Fraxinus,

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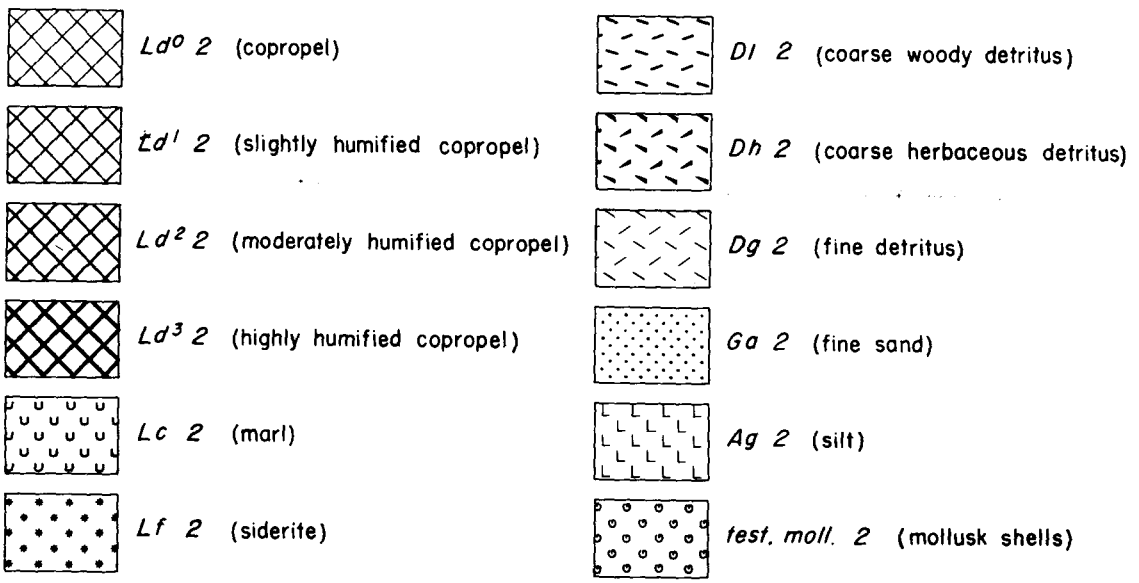
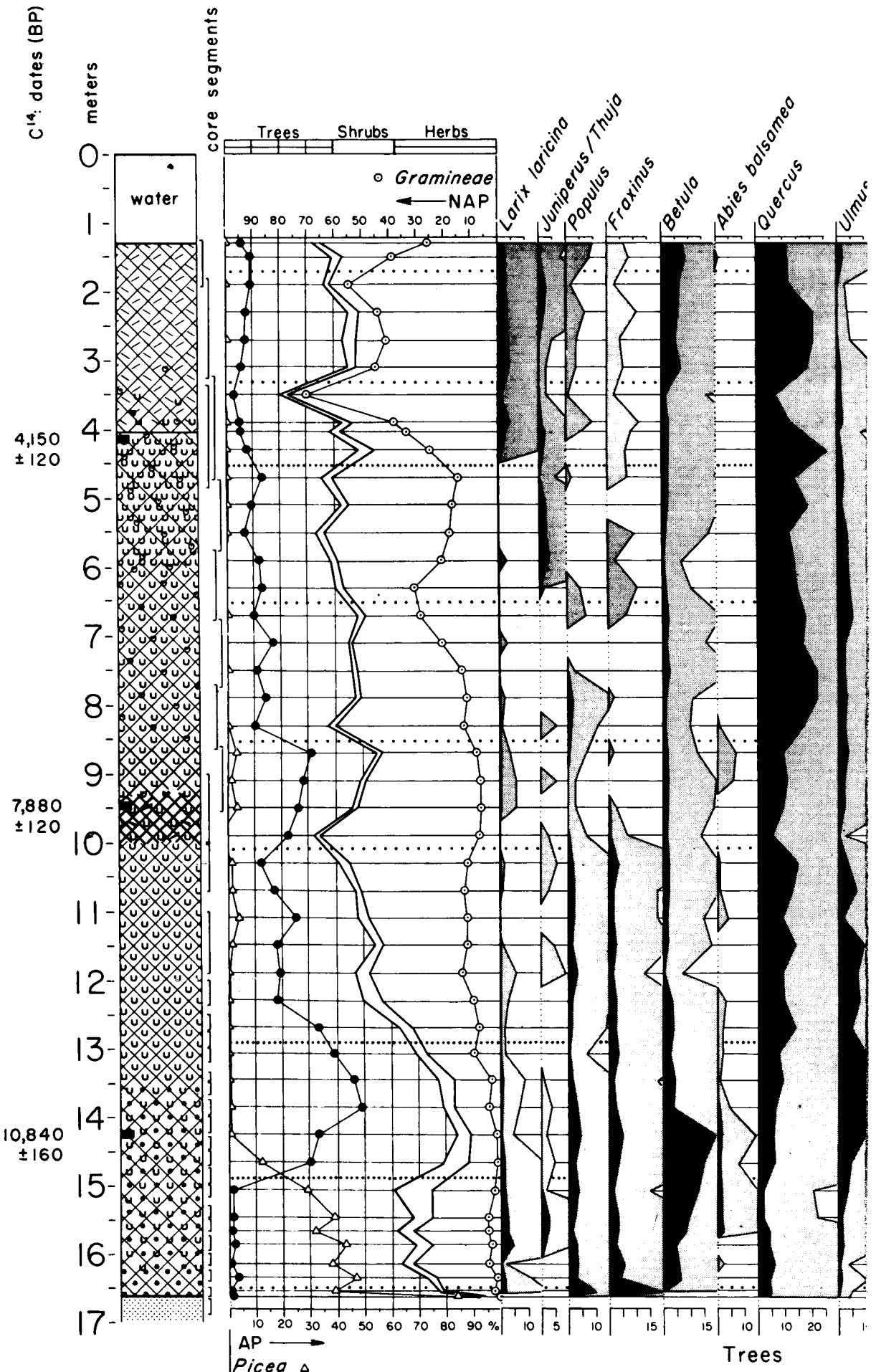
[2]Pyrite occurs both as cubic and octahedral crystals 1 to 4 μ in diameter and as spheroidal crystalline aggregates like the "black spheres" of Vallentyne and Swabey (1955).

Figure 3. Pollen diagram of Cedar Bog Lake. Scale at base of diagram gives percentages for black silhouettes; stippled silhouettes are exaggerated 10X scale. Abbreviations: AP = arboreal pollen, NAP = non-arboreal pollen, undiff. = undifferentiated, Petalostemum cand. = P. candidum, Polygonum lapath. = P. lapathifolium, Lycopodium complan. = L. complanatum, Indet. = indeterminable, Unident. = unidentifiable. Symbols used in the sediment lithology column are given below.

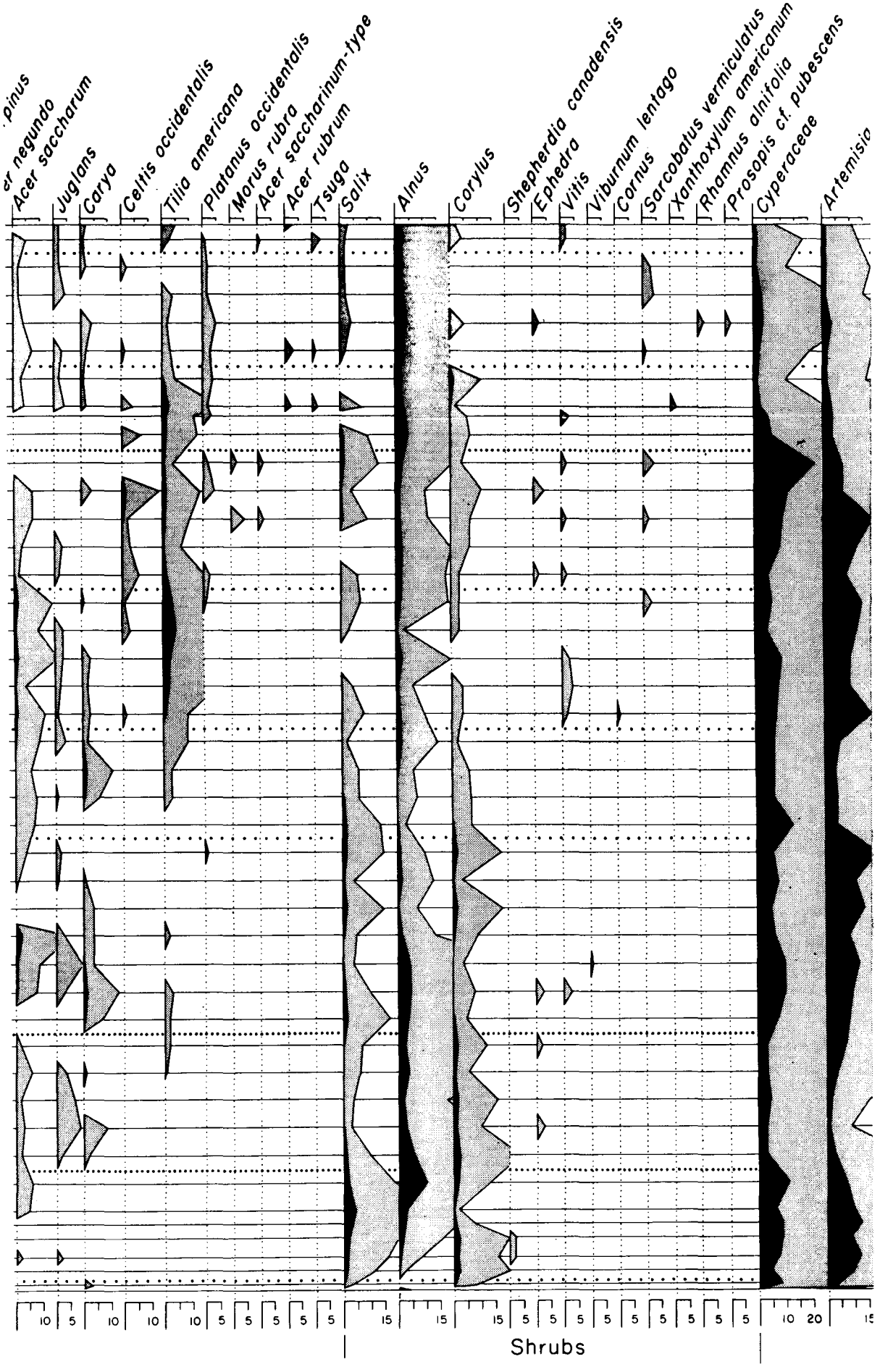


Density of symbols indicates proportion of component in the sediment. Density shown here indicates a proportion of 50%.

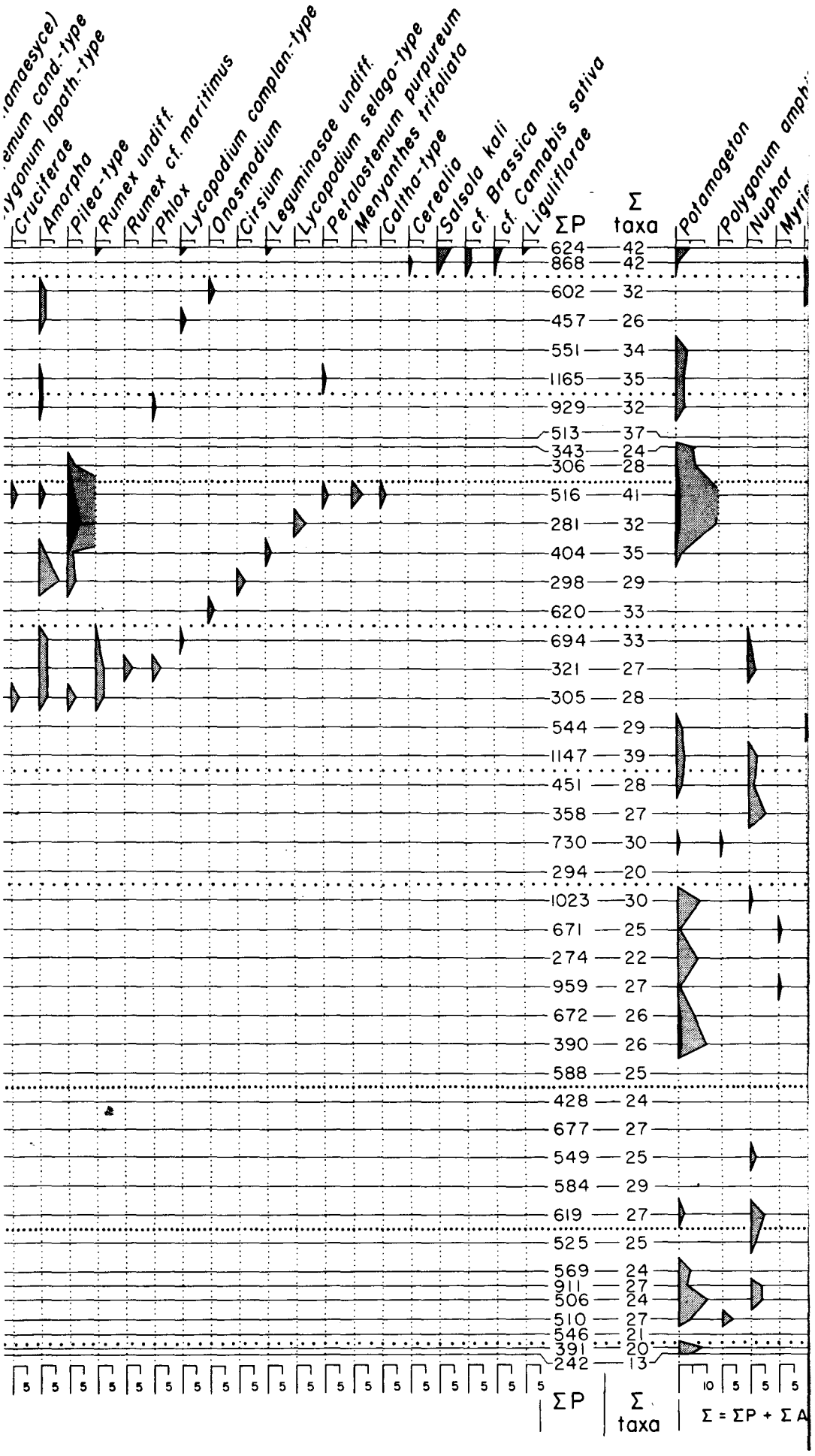
CEDAR BOG LAKE Anok

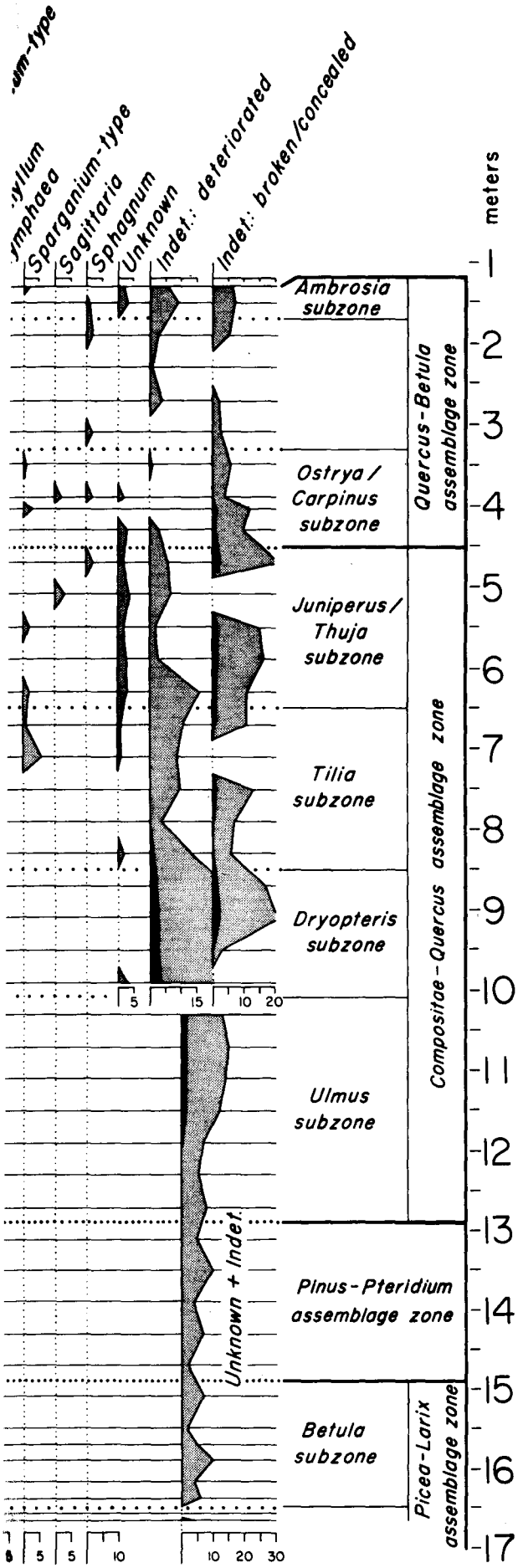


Co., Minnesota



Tubuliflorae undifferentiated
Ambrosia-type
Iva ciliata-type
Iva xanthifolia-type
Xanthium
Chenopodium-type
Urtica-type
Equisetum
Dryopteris-type
Pteridium aquilinum
Humulus lupulus
Laportea-type
Thalictrum
Typha latifolia
Selaginella
Rosaceae
Ericaceae-type
Epilobium
Scheuchzeria
Galium
Lycopodium undiff.
Caryophyllaceae
Decodon verticillatus
Osmunda
Umbelliferae
Euphorbia
10 20 30 40 50 60 70
10 5 5
10 20
10 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
Herbs


Cruciferae
Amorpha
Pilea-type
Rumex undiff.
Rumex cf. maritimus
Phlox
Lycopodium complan.-type
Onosmodium
Cirsium
Leguminosae undiff.
Lycopodium selago-type
Petalostemum purpureum
Menyanthes trifoliata
Caltha-type
Cerealia
Salsola kali
cf. Brassica
cf. Cannabis sativa
Liguliflorae
Potamogeton
Polygonum amph
Nuphar
ΣP
Σ taxa
624 42
868 42
602 32
457 26
551 34
1165 35
929 32
513 37
343 24
306 28
516 41
281 32
404 35
298 29
620 33
694 33
321 27
305 28
544 29
1147 39
451 28
358 27
730 30
294 20
1023 30
671 25
274 22
959 27
672 26
390 26
588 25
428 24
677 27
549 25
584 29
619 27
525 25
569 24
911 27
506 24
510 27
546 21
391 20
242 13
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
ΣP
Σ taxa
10 5 5 5
Σ = ΣP + ΣA



anal. E.J. Cushing, 1959-1962

Juniperus/Thuja, and Abies. Pinus pollen is relatively infrequent. The zone is elsewhere divided into two subzones, but only the upper one, the Betula subzone, is recognized at Cedar Bog Lake.

Pinus-Pteridium assemblage zone.

Pinus is the dominant pollen type in this zone, and the pollen of herbs is relatively low. A number of deciduous trees and shrubs are well represented in the zone; prominent among these are Betula, Ulmus, Populus, Fraxinus, and Alnus. Spores of Pteridium aquilinum attain relatively high percentages and are as characteristic of the zone as Pinus pollen. Betula pollen attains a maximum frequency in the lower part of the zone, and pollen of Ulmus and Quercus reaches high values in the upper part.

Compositae-Quercus assemblage zone.

The pollen of herbs dominates this zone. Gramineae, Artemisia, Ambrosia and other Tubuliflorae, and Chenopodium-type all occur in relatively high pollen percentages, and fluctuations in the percentages are conspicuous. Of the trees, Quercus and Pinus are the most important pollen contributors. The base of the zone is defined by the gradual but prominent increase in pollen of Gramineae, Artemisia, Ambrosia and other Tubuliflorae, and Chenopodium-type; at Cedar Bog Lake it is placed somewhat arbitrarily at a sharp decline in the relative frequency of Ulmus pollen. The zone is divided into four subzones.

Ulmus subzone. This subzone occurs at the base of the Compositae-Quercus zone. Ulmus is a relatively important tree-pollen type, although exceeded in amount by Pinus and Quercus. Fraxinus, Populus, Acer saccharum, and Alnus all contribute relatively much pollen.

Dryopteris subzone. Sharply-defined maxima in Pinus pollen and Dryopteris-type spores characterize this subzone. Picea, Larix, and Abies show slight increases, as do Typha latifolia and Chenopodium-type. The subzone is delimited by the abrupt rise of Pinus at the base and its equally abrupt fall at the top.

Tilia subzone. Quercus is the dominant tree pollen type in this subzone, and is joined by relatively high values of Tilia. Acer saccharum and Ostrya/Carpinus increase slightly. The base of the subzone is placed at an abrupt rise in the percentage of Quercus pollen.

Juniperus/Thuja subzone. Quercus continues to dominate the tree pollen in this subzone, and Juniperus/Thuja pollen rises to relatively high values. Tilia and Ostrya/Carpinus pollen is relatively infrequent. Artemisia, Chenopodium-type, and Pilea-type have prominent maxima within the subzone, which extends from the abrupt rise of Juniperus/Thuja pollen to the top of the zone.

Quercus-Betula assemblage zone.

The tree pollen in this zone is dominated by Quercus, and Betula pollen is relatively common. Pollen of Artemisia is relatively infrequent, as are the Ambrosia-type and Chenopodium-type, except in the uppermost subzone. At Cedar Bog Lake, but not necessarily elsewhere, Gramineae supply the dominant pollen type, and Larix, Juniperus/Thuja, and Ostrya/Carpinus also contribute relatively high percentages. The top of the zone is the sediment-water interface; the base is defined by a sharp increase in the percentage of Quercus pollen that follows the decrease of Artemisia and Chenopodium-type pollen percentages at the top of the next lower zone. Two intervals within this zone are given subzone names.

Ostrya/Carpinus subzone. This subzone is marked by a broad peak in the pollen of Ostrya/Carpinus, with less prominent maxima in the pollen curves of Tilia, Populus, and Corylus. Larix and Alnus rise to relatively high percentages at the base of the subzone, and grass pollen increases dramatically. The subzone is at the base of the Quercus-Betula zone, and its top is placed at a sharp increase in Betula pollen after the decline of Ostrya/Carpinus. An unnamed interval separates it from the Ambrosia subzone.

Ambrosia subzone. A high relative frequency of Ambrosia-type and Chenopodium-type pollen marks this subzone. Small amounts of pollen of other agricultural weeds and cereal grasses are also characteristic. The subzone occupies the upper 20 to 50 cm of sediment, above the sharp rise in Ambrosia-type percentages.

Inferred vegetation history

Picea-Larix and Pinus-Pteridium zones.

The Picea-Larix and Pinus-Pteridium zones of the present diagram of Cedar Bog Lake are quite similar in their general character to those zones at the other sites (Horseshoe Lake and Andree Bog) of this study and will be discussed in detail together with those diagrams. Only a brief summary of the interpretation is given here. The vegetation in the area surrounding Cedar Bog Lake is believed to have been dominated by Picea when the lake basin formed. Openings in the spruce forest were common, perhaps partly maintained by a combination of landscape instability and natural disasters. Populus balsamifera (balsam poplar) and Populus tremuloides were common occupants of these openings, and prairie elements, including Artemisia species, grasses, and Ambrosia species, may have occurred on the drier sites. Larix

laricina, Thuja occidentalis or Juniperus species, and Abies balsamea (balsam fir) were possible associates of Picea, and Quercus species may have grown on favorable sites. Fraxinus nigra was an important tree in moist depressions on the Sand Plain.

A rapid warming of the climate encouraged a succession on the uplands that is recorded in the transition to the Pinus-Pteridium zone. Betula replaced the Picea stands and was in turn succeeded by Pinus on the drier sites and deciduous forests dominated by Ulmus on the more mesic sites.

Interpretation of the pollen zones above the Pinus-Pteridium zone is rendered more difficult by the lack of near-by detailed pollen diagrams for comparison. The nearest sites for which sufficiently detailed diagrams have been prepared are Kirchner Marsh (Winter, 1961) and Lake Carlson (Patten, 1959), both in Dakota County, Minnesota, about 40 miles south of Cedar Bog Lake. Nevertheless, in spite of the distance and the edaphic differences between these sites and Cedar Bog Lake, the three share the same general characteristics of pollen stratigraphy. The same pollen zones can be recognized at all three, and this fact increases confidence in the interpretation that follows.

Compositae-Quercus zone.

The transition from the Pinus-Pteridium zone to the Compositae-Quercus zone is marked by a gradual decline in pollen of Pinus, the rise of herb pollen, and the shift in dominance from Ulmus to Quercus pollen. In the Ulmus subzone of the Compositae-Quercus zone these trends continue. They suggest a gradual shift from a pine-dominated forest to a mesic hardwood forest with abundant elm and an increasing representation of oak. Such a change could have resulted from a northward movement of the tension zone that at present separates the

prairie-forest floristic province from the northern hardwoods province in Wisconsin and Minnesota (Curtis, 1959). The careful description of Wisconsin plant communities by Curtis (1959) provides a useful frame of reference for evaluating the shifts in the pollen diagram. A community similar to Curtis' northern dry or dry-mesic forest probably contributed to the Pinus-Pteridium zone. Pine, probably Pinus resinosa or P. banksiana, dominated the community, and the understory contained abundant Pteridium aquilinum (bracken). Stands of northern mesic forest, with Ulmus a prominent component, were interspersed with the pine forest. Acer saccharum, Tilia americana, Carya, and Juglans were also probably present in the mesic forest, although the low pollen percentages suggest they were minor components.

The presence of abundant Ulmus pollen suggests that fire was not an important environmental factor during the deposition of the Ulmus subzone, for elm has low resistance to repeated burning. In the absence of fire a succession from pine forests to mesic hardwood forests is expectable, and this succession is a reasonable explanation for the slow decline of Pinus pollen in the transition from the Pinus-Pteridium to the Compositae-Quercus zone.

The gradual but steady increase in the pollen of Quercus and of herbs during the Ulmus subzone suggests the slow replacement of mesic forests by xeric forest and prairie. The change from pine to oak as the dominant tree of the postulated xeric forest implies a shift from Curtis' northern dry forest to southern dry forest, which means that the tension zone between the two floristic provinces moved north past Cedar Bog Lake during the deposition of the Ulmus subzone. The oak and prairie herbs may at first have directly succeeded pine forest on the driest sites in the region. Later the southern dry

forest and prairie began replacing the mesic elm forest as well. The overall vegetation of the region during the time of the Ulmus subzone is thus visualized as a mosaic of mesic hardwood forest with gradually enlarging oak savannas and prairie openings. Since the pollen of Fraxinus remains relatively high throughout the interval, it is probable that ash was an important occupant of the poorly drained lowlands, accompanied on wetter sites by Alnus. Pinus undoubtedly remained as isolated stands or individuals in favorable microhabitats, and Abies, Picea, and Larix apparently also persisted, for their pollen grains recur constantly.

Remarkably, Fraxinus and Ulmus remained important contributors to the pollen rain throughout this interval of increasing temperature and dryness. Their persistence may reflect the stability of the mesic and wet-mesic forests; once thoroughly established, these communities resist invasion because they create and maintain their own environment. An alternative explanation postulates the continuous shifting of the communities along the moisture gradient. If--to continue the terminology of Curtis--the inferred communities in the Cedar Bog Lake area at the beginning of the Compositae-Quercus zone are placed in order along a moisture gradient from very dry to very wet habitats, the arrangement would be: (1) oak openings (important contributors to the pollen rain: Quercus, grasses, Artemisia, Ambrosia); (2) southern mesic forest (Ulmus, Acer saccharum, Tilia, Carya, Juglans); (3) wet-mesic forest (Ulmus, Fraxinus); (4) alder thicket (Alnus). An increase in temperature and decrease in available moisture might result in the expansion of the first community and the reduction of the last, with the intermediate communities being displaced along the gradient but undergoing no marked change in areal extent. The

sharp decrease in Alnus in the middle of the Ulmus subzone may reflect just such a shift. The communities dominated by Ulmus and Fraxinus, however, maintained their areal importance until the interval of maximum climatic stress, when they decreased abruptly, never to recover fully.

The interval of maximum dryness is believed to be represented by the Dryopteris subzone. This part of the pollen diagram is peculiar in several respects. First, it coincides with a prominent lithologic unit, the "dark gyttja" layer of Lindeman (1941a). The layer, also observed by Swain (Swain and Prokopovich, 1954; Swain and others, 1959), clearly indicates changed conditions in the lake, but its significance has been in doubt. In the present core, the sediment is a fine-detritus marly copropel 70 cm thick, highly humified at the base but decreasingly so upward. The organic detritus consists of unidentifiable cellular fragments. Charcoal is present in relatively high amount. Coarse mineral silt is also relatively more common than in the sediments above and below. All of these components are most abundant at the bottom of the layer and decrease in amount upward as the sediment grades into marly copropel.

The pollen content of the sediment is also peculiar. The peak of Dryopteris-type spores is the most striking feature of the pollen diagram (fig. 3), but it is clear that Pinus also increases in the interval. These changes are not known from either of the two diagrams from Dakota County, although the Compositae-Quercus zone is well marked in both. This fact, together with the close association of the peculiar pollen types with a local lithologic unit, suggests a local origin for the types. The few fern spores that could be positively identified were those of Dryopteris thelypteris (marsh fern),

and it is highly probable that an overwhelming proportion of the Dryopteris-type spores were derived from that species. Of the pine pollen, about one-third in one sample from the subzone is Pinus strobus-type, and the remainder is Pinus banksiana or P. resinosa (table 1, p. 23).

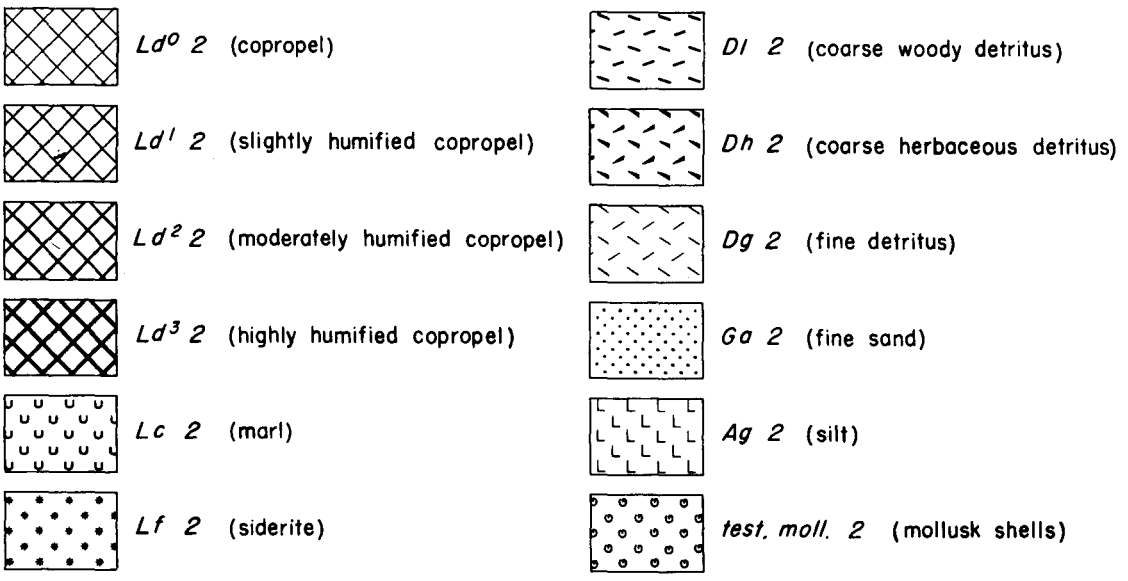
Minor but significant increases in the subzone are shown in the pollen curves of Typha latifolia, Chenopodium-type, Cyperaceae, Picea, and Larix. The percentage of indeterminable grains rises sharply as a result of corrosion of the pollen; the fern spores in particular tend to be corroded.

Because the Dryopteris-type spores occur in such quantity in the Dryopteris subzone, they tend to mask the curves of other contributors to the pollen rain. In the special diagram (fig. 4), these spores have been omitted from the pollen sum in the subzone, together with Cyperaceae pollen. The rise in Pinus is revealed more clearly as a result.

The increased amount of Pinus and Picea pollen in this subzone suggests the possibility of erosion and redeposition of sediments from the Picea-Larix and Pinus-Pteridium zones. Such redeposition of sediment derived from another part of a lake basin is not unknown; a diagram from Seidel Lake, Wisconsin, by West (1961) gives an excellent example. This explanation cannot be applied in the present case, however, as examination of the pollen diagram reveals. Significant amounts of Pinus and Picea pollen could not be eroded from the earlier zones without the incorporation of Betula and Ulmus pollen as well, and these types show no increase in the Dryopteris subzone.

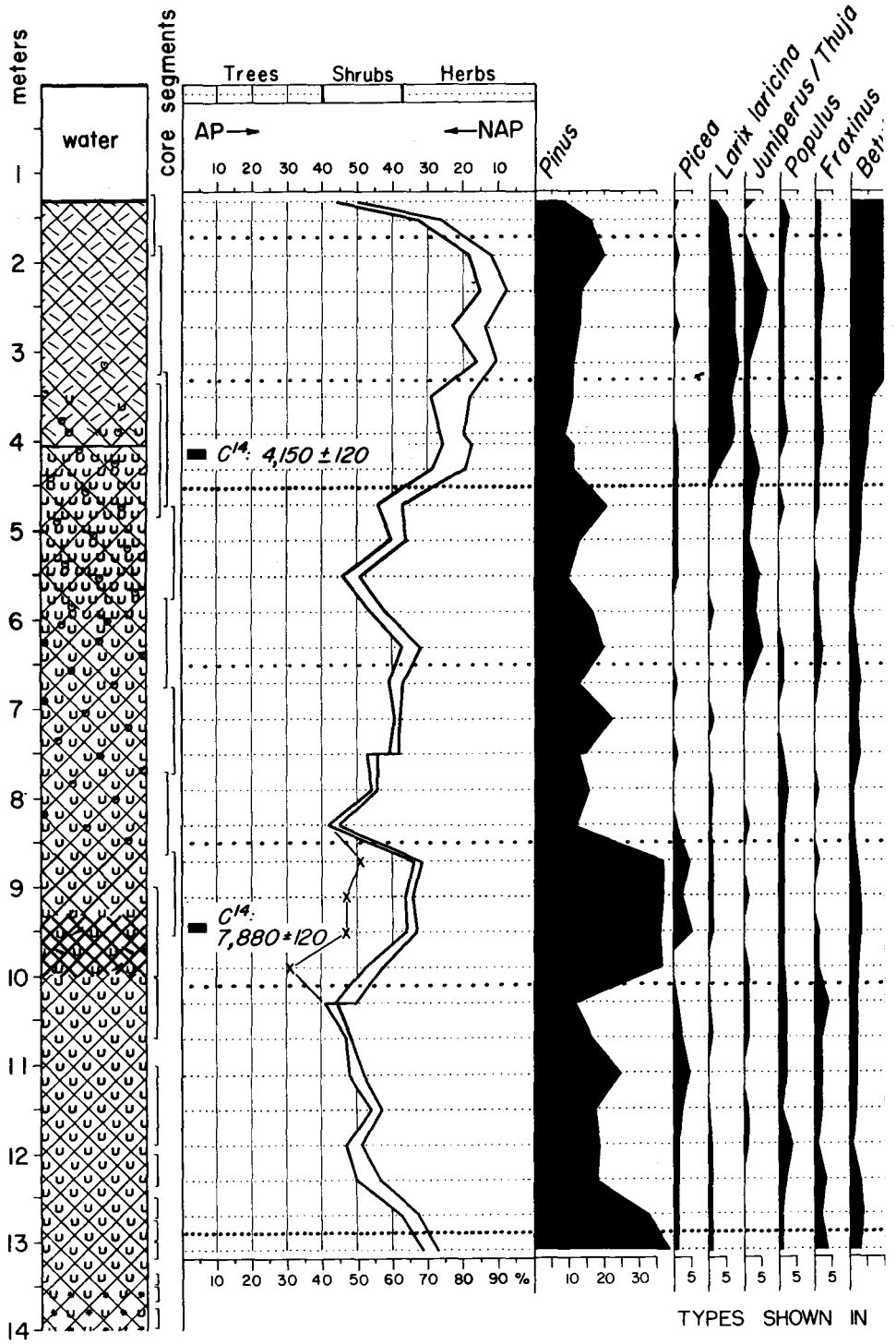
The best explanation for the peculiarities of the Dryopteris subzone is the lowering of the lake level and the development of new

Figure 4. Special pollen diagram of Cedar Bog Lake. The pollen sum is the same as in the main diagram (fig. 3), except that types shown in white silhouettes are excluded from the sum on which the types shown in black silhouettes are calculated. Symbols used in the sediment lithology column are given below.

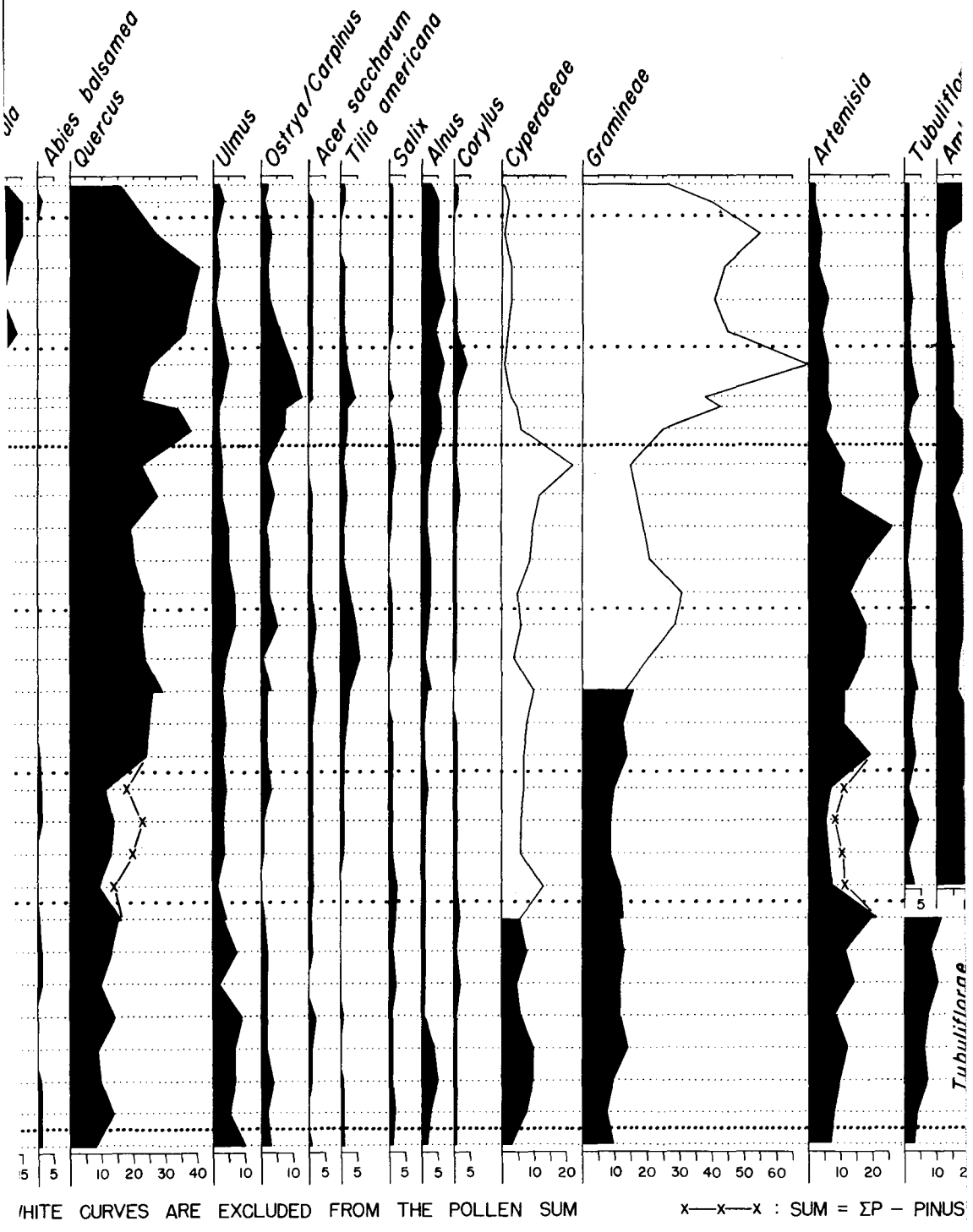


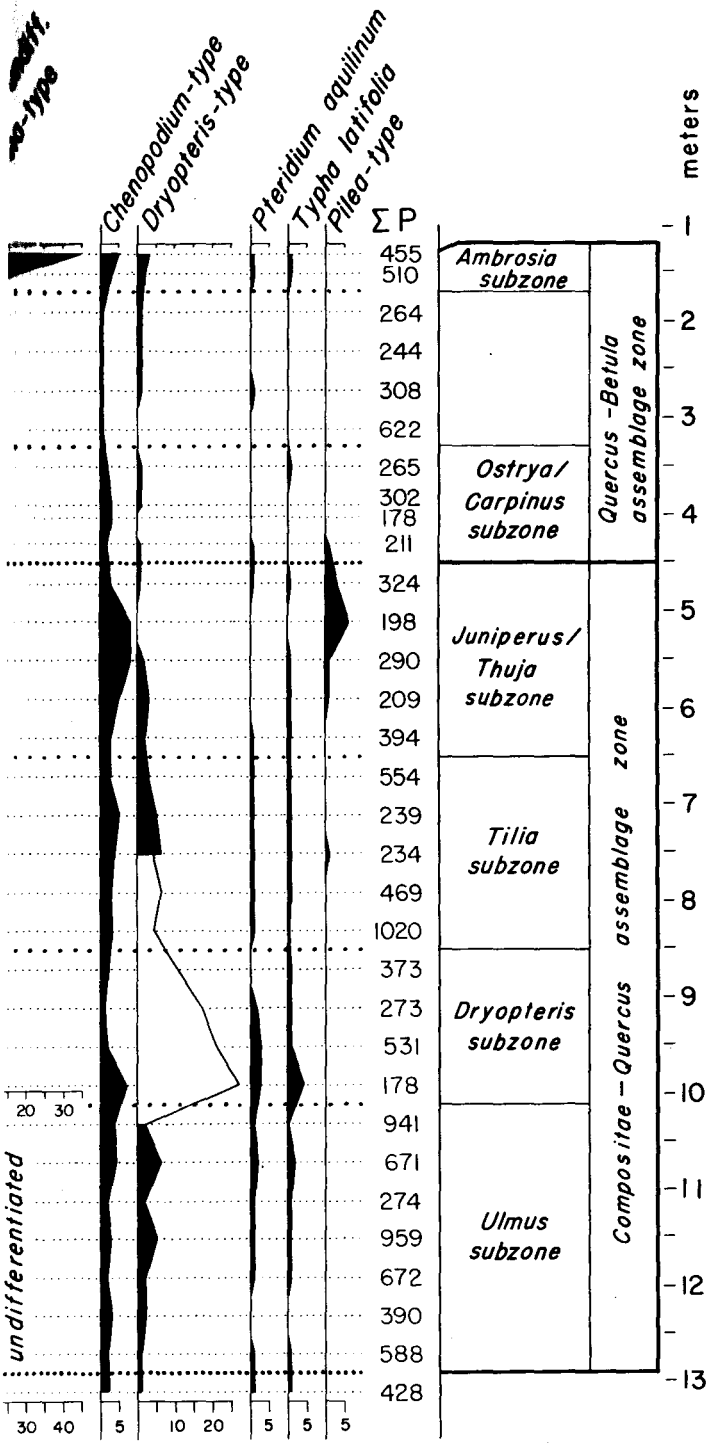
Density of symbols indicates proportion of component in the sediment. Density shown here indicates a proportion of 50%.

CEDAR BOG LAKE Anoka



Co., Minnesota




undifferentiated
Chenopodium-type
Dryopteris-type
Pteridium aquilinum
Typha latifolia
Pilea-type
ΣP
meters
455
510
264
244
308
622
265
302
178
211
324
198
290
209
394
554
239
234
469
1020
373
273
531
178
941
671
274
959
672
390
588
428
Ambrosia subzone
Ostrya/ Carpinus subzone
Juniperus/ Thuja subzone
Tilia subzone
Dryopteris subzone
Ulmus subzone
Quercus-Betula assemblage zone
Compositae-Quercus assemblage zone
1
2
3
4
5
6
7
8
9
10
11
12
13
20 30
30 40
5
10 20
5
5
5

plant communities on the exposed lake shores and bottom. Because of the irregular shape of the lake basin, a lowering of water level could easily have exposed considerable lake bottom in shallow former bays. The resulting shallow water and mud flats would provide good habitats for cat-tail marshes and wet sedge meadows, with Dryopteris thelypteris a prominent component of the latter community. Chenopods might also have found ideal growing conditions on the exposed rich sediments. Picea mariana and Larix laricina perhaps found favorable sites on local sedge mat.

The abandoned beaches of the lake may have been invaded by Pinus resinosa and P. strobus, species which probably could not compete with the prairie and oak openings on the uplands. The presence of charcoal in the sediment suggests that fire may have been an important selective agent, and Pinus banksiana might have been favored in burned areas.

This reconstruction of conditions during the Dryopteris subzone is illustrated in figure 5c. The highest occurrence of the dark marly copropel layer in Lindeman's transect section of the sediments (fig. 5a) was considered as the water level at the beginning of the subzone. Whether the lithology of the layer changes laterally across the bog is unknown, but it is possible that in the southeast part of Lindeman's transect the "dark gyttja" is in fact a decomposed sedge or marsh peat, and this is suggested in the drawing. Nuphar (yellow pond-lily) pollen is present in the subzone, and that plant is shown in the shallow water, together with emergent aquatics such as Scirpus (bulrush) and Typha latifolia. Closer to the upland a Carex-Dryopteris thelypteris community is shown, with bog conifers (Picea mariana, Larix laricina, and possibly Pinus strobus) occurring on slightly

drier sites. The exposed sandy shores of the lake are occupied by Pinus, and prairie with a scattering of Quercus is on the uplands beyond.

It is unlikely that Cedar Bog Lake ever dried up completely during this or any other interval in its history. Marl deposition apparently continued in the center of the lake throughout the interval, and planktonic algae are present in the sediment at all levels examined. The suggested interpretation adequately explains the nature of the dark marly copropel layer, however. Humic compounds and partly decomposed plant fragments, probably together with fern spores and pollen grains corroded by oxidation, were washed into the center of the lake from the extensive sedge marsh that fringed it. Mineral grains were blown in or were washed in from the steep northwest side of the basin.

The marked lowering of lake level--about four meters below the present level--must have been the result of a prolonged period in which evaporation exceeded precipitation. Both temperature and precipitation were undoubtedly factors, and their relative importance cannot be assessed from the evidence now at hand. It seems likely, however, that the time of the lowest water level at the base of the Dryopteris subzone was decided by a relatively short-term climatic fluctuation--perhaps a decrease in mean annual precipitation--superimposed on a longer period of climatic change, most likely one of increasing temperature. The evidence for the gradual shift is seen in the Ulmus subzone, and the period of low water level is only one relatively short oscillation in the Compositae-Quercus zone as a whole.

The gradual upward decrease in many of the characteristics of the lowest level of the Dryopteris subzone--the decrease in humicity,

mineral grains, plant fragments, and spores of Dryopteris thelypteris--suggests a gradual reduction in the conditions responsible for these peculiarities, namely a rise in water level in the lake. The abrupt decrease in Pinus pollen at the end of the subzone, just when the characteristics mentioned reached levels similar to those in the preceding subzone, can be logically explained by the drowning of the pine trees that were postulated to grow on the shores exposed by the drop in water level. Perhaps the sapropsammite deposit noted by Lindeman on the flanks of the basin is an organic beach deposit dating from the period of higher water level following the time of the Dryopteris subzone; at least the sapropsammite at the northwest side of the basin (fig. 5a) must be younger than the dark copropel, if Lindeman's stratigraphy is correct.

There is no evidence that the water level in Cedar Bog Lake again dropped so low as during the time of the Dryopteris subzone, although minor fluctuations in water level probably affected the subsequent development of the surrounding bog.

Quercus pollen increases in relative frequency at the end of the Dryopteris subzone and remains relatively high in the next interval, the Tilia subzone. The relatively low values for Quercus in the Dryopteris subzone are to some degree attributable to the abundance of Pinus pollen and Dryopteris spores, and if both these plants grew locally in the Cedar Bog Lake basin their pollen and spores distort the regional pollen rain, which may have been dominated by Quercus. Figure 4 shows by a supplementary curve (X's) the effect on the percentages of Quercus pollen of the removal of Pinus as well as Dryopteris and Cyperaceae from the pollen sum; when this is done it can be seen that Quercus pollen in fact rises steadily through the Dryopteris

subzone. The high relative frequency of Quercus pollen, together with high percentages of Gramineae, Compositae, and Chenopodium-type, suggests that the uplands in the Cedar Bog Lake area were chiefly prairie, with a representation of the oak-dominated communities that Curtis (1959) calls the oak opening and oak barrens. It is in the Tilia subzone that pollen of the typical prairie legume genera Petalostemum and Amorpha were first noticed. Petalostemum candidum and Amorpha canescens are common in xeric prairie or dry woodland habitats (Curtis, 1959), and both occur in abandoned fields in the area today.

The Tilia subzone is marked, however, by pollen of trees suggesting more mesic conditions than the picture just sketched. Tilia pollen is the first to reach a maximum, followed by maxima in Acer saccharum, Ostrya/Carpinus, and Ulmus. This sequence suggests a succession toward increasing mesic conditions, with Tilia americana, a species that has high importance in dry-mesic stands (Curtis, 1959), invading an oak stand and being in turn replaced by the more moisture-demanding species Acer saccharum and Ulmus americana (or Ulmus rubra). This succession probably did not occur on the general upland surface but rather in limited and favorable habitats. Perhaps the small knolls close to the present lake (fig. 2) supported stands of these trees sufficiently close to the site of the pollen core to contribute all of the pollen of the mesic species. These knolls, which at that time may have been islands in the lake, could have provided local habitats with moist soil and protection from fire that would be favorable to a maple-basswood community. The succession may even have been aided by a rise in lake level and a concomitant increase in soil moisture.

The pollen contributed by this mesic community declines in relative frequency in the next higher subzone, however, and the pollen of herbs increases. Quercus retains its importance in the Juniperus/Thuja subzone, but the increase in pollen of Artemisia and Chenopodium-type suggests another cycle of increased dryness that favored these species on the upland or around contracted lakes.

The increase in pollen of Juniperus/Thuja in the subzone creates a problem in interpretation. It might reflect the development of a local community with Juniperus a prominent member, like the cedar glade community of Curtis (1959). The explanation preferred here, however, is that the pollen is that of Thuja occidentalis, and its rise in the subzone signals the initiation of the present Thuja-dominated bog forest, perhaps a response to the attainment of a new equilibrium in lake level. This interpretation gains support from the prominent maximum of Pilea-type pollen. Pilea pumila (richweed) is today a common understory herb in the Thuja forest surrounding Cedar Bog Lake; although small and inconspicuous, it is presumably wind-pollinated like other members of the Urticaceae, and if present in quantity in a forest site bordering the lake it could conceivably contribute much pollen to the lake sediment. Pollen identified as that of Laportea canadensis (wood-nettle) also appears in the subzone, but the pollen of the two genera is similar, and the parallelism of their curves suggests a difficulty in identification. The inference that bog forest was present during the time of this subzone is supported by finds of Menyanthes and Caltha-type pollen; both Menyanthes trifoliata (buckbean) and Caltha palustris (marsh-marigold) are common in the Thuja forest today.

Another problem is the interpretation of the high percentages of pollen of Gramineae in the lower part of the Juniperus/Thuja subzone. If the pollen was contributed by upland grasses, the rise and prominent maximum may record an increase in prairie or a succession of prairie communities, with new species of grass becoming dominant. On the other hand, the pollen might have derived from aquatic grass species, such as Zizania aquatica (wild rice), Calamagrostis canadensis (blue-joint), or Phragmites communis. In the latter case, the rise and decline in the curve might reflect a change in water depth in some bay of the lake. There is no way to decide from the evidence now available which of these explanations is the correct one. In figure 4 Gramineae has been removed from the pollen sum, beginning at the point in the Quercus-Tilia subzone where the curve starts to rise to the maximum in question. If the fluctuation in Gramineae pollen is indeed due to shifts in local aquatic grass populations then its effect on the other curves is eliminated by this modification.

The sharp maximum in Cyperaceae pollen at the top of the Juniperus/Thuja subzone is probably the result of a local increase in an aquatic sedge, perhaps Scirpus. For that reason it, too, has been left out of the pollen sum in figure 4.

Quercus-Betula zone.

A number of significant changes mark the transition from the Compositae-Quercus to the Quercus-Betula zone. The most obvious is a huge increase in pollen of Gramineae, which dominates the upper zone. This increase is accompanied by an equally marked decrease in the pollen of the other herbs with which Gramineae pollen was associated in the preceding zone: Artemisia, Ambrosia-type, and Chenopodium-type. The negative correlation between the pollen frequency of grasses and

the normal prairie associates of grasses immediately suggests that the increase in grass pollen was not due to an extension of prairie but rather to some local event.

It seems reasonable to infer that this event was the spread of Zizania aquatica in the lake basin. Although absent or very rare in the lake today, Zizania has been collected and recorded by several observers at Cedar Bog Lake, notably Buell and Buell (1941), who reported that following a severe drought in 1934 Zizania aquatica was growing on a "broad expanse" of sediments in the present lake. The fossil pollen in question agrees well with pollen of Zizania aquatica, although not all other grass species can be eliminated. Finally, Wilson and Potzger (1943), in their study of a number of lakes on the Anoka Sand Plain, made special mention of high values of grass pollen (up to 75 percent of total pollen) that they found at some sites, particularly Island Lake and Tamarack Lake, two shallow lakes about six miles southeast of Cedar Bog Lake that they reported to be filled with Zizania aquatica. Diagrams from deeper lakes on the Sand Plain, as well as from the bog sites studied by Artist (1939), show only a slight increase in pollen of Gramineae in the upper sediments or none at all, and Wilson and Potzger concluded that local stands of wild rice were responsible for the high values of grass pollen they observed.

Since the bulk of the Gramineae pollen is believed to represent local stands, Gramineae pollen has been subtracted from the pollen sum in figure 4.

The decline of pollen of prairie herbs and the sharp rise in Quercus pollen that defines the bottom of the Quercus-Betula zone suggests a widespread invasion of the prairie by oak. Perhaps the oak openings and oak barrens postulated for the previous zone extended

their area, and the vegetation of the uplands changed from prairie with local groves of oak (Quercus ellipsoidalis and Q. macrocarpa) to an open oak woodland with local remnants of prairie.

The marked increase in pollen of Ostrya/Carpinus that characterizes the Ostrya/Carpinus subzone is puzzling. Perhaps the best explanation is a return of mesic forest in local habitats like those postulated in the Tilia subzone of the previous zone. If Ostrya virginiana remained as scattered individuals on these sites after the decline of Tilia, Acer, and Ulmus during the time of the Juniperus/Thuja subzone, an increase in the ratio of precipitation to evaporation might have allowed the Ostrya to form an open canopy before the other mesic trees displaced it. Under these circumstances a few trees might flower freely and produce an amount of pollen greatly exceeding the pollen production of the species in its usual sub-canopy position.

Important local changes besides the growth of Zizania were occurring at Cedar Bog Lake at about the same time as these inferred changes in upland communities. The increase in Alnus and Larix pollen clearly reflect the development of the bog forest. Spores of Sphagnum and Osmunda, probably derived from the surrounding bog, also make an appearance. Concomitant with the appearance of Larix pollen in the sediments is a marked change in lithology: the marl content drops abruptly, producing a sharp contact between copropelic marl (below) and marly copropel (above), and then continues to decrease gradually until the uppermost 1½ meters of lake sediment have no observable content of carbonate. The simplest explanation of the decrease in carbonate deposition is a reduction in supply of mineral-bearing waters from the upland to the lake as a result of the centripetal growth of the bog forest. The fluctuation in pollen percentages of the Juniperus/

Thuja type (surely mostly Thuja occidentalis) is unexplained; perhaps variations in water level have an effect on the pollen production of the species.

Figure 5b illustrates the inferred conditions at about the time of the base of the Quercus-Betula zone.

The increase in Betula pollen in the upper part of the zone is not understood. It may reflect the local development of birch (Betula pumila var. glandulifera or B. papyrifera or B. lutea) on or around the bog, or it might be due to an increase of Betula papyrifera on the uplands, perhaps as a successional stage in the closure of the postulated oak openings. Betula occurs today both on upland and lowland sites in the area, but its relative contribution to the pollen rain from the two types of habitat is unknown.

A comparison of the pollen spectra immediately below the Ambrosia subzone with what is known of the pre-settlement vegetation of the area is revealing. Pierce (1954) reviewed the available information for the township that includes Cedar Bog Lake, and Rand (1953) did the same for the townships immediately to the east and southeast. Based largely on surveyor's records made during the public land survey in the 1850's, both studies agree in their conclusion that the vegetation at that time was similar floristically to the vegetation today, but that the upland woodlands were more open than at present. The upland vegetation as described by the surveyors was chiefly oak openings or oak scatterings with black oak (Quercus ellipsoidalis), bur oak, and a considerable amount of "scrub oak" (fire-stunted oak), interspersed with occasional open prairies. Pines were scattered throughout the area, apparently much as they are today. Lowlands were occupied by tamarack swamp, alder swamp, willow swamp, marsh, and

meadow. Thuja occidentalis was apparently as rare in Anoka County outside Cedar Creek Bog then as it is today.

It is believed that the open character of the vegetation and the prevalence of scrub oak in the descriptions of the pre-settlement vegetation are a result of a higher frequency of fire in the area before European settlement. Curtis (1959) ably reviews the evidence in support of this hypothesis as applied to similar situations in Wisconsin. The pollen diagram offers no direct support of this hypothesis. Unfortunately the influence of Zizania pollen conceals the pollen contribution that may have been made by upland grass communities, and no estimate of its amount is possible. The marked decrease in pollen of other herbs (especially Artemisia and Ambrosia-type) at the top of the Compositae-Quercus zone might be the result either of a decrease in area occupied by prairie (invasion by oak), or a shift in the character of the prairie from a xeric to a more mesic type. The fact that some pollen of prairie herbs persists in the Quercus-Betula zone (Amorpha, Petalostemum candidum-type, Petalostemum purpureum, Onosmodium) suggests that at least remnants of the prairie were still present, and a combination of the two possibilities may be closest to the truth.

The increase of Ambrosia-type pollen that characterizes the Ambrosia subzone reflects the great increase in soil disturbance that accompanied European settlement and cultivation. The presence of other weed pollen types (Chenopodium-type, Salsola kali (Russian thistle), cf. Brassica (mustard), and cf. Cannabis sativa (hemp)) and cereal pollen (probably Zea mays, corn) confirms the interpretation. According to Pierce (1954), settlement in the area began in 1856.

Infrequent pollen grains.

Most of the preceding interpretation of the pollen diagram from Cedar Bog Lake has been based on changes in relative frequency of the most abundant pollen types. The interpretation of rare and infrequent pollen types is always a difficult task, especially when nearby detailed diagrams are not available for comparison. The lack of information about local and regional variation in the composition of the fossil pollen rain makes it difficult to evaluate the significance of a few grains found at a single point, for they may have been blown in from far away and may have no relationship to the vegetation immediately surrounding the spot where they were deposited. In the present case, the difficulty is further increased by an imperfect knowledge of the stratigraphic range of some of the pollen types, because the pollen counts were made at different times and for that reason are of varying quality. The upper half of the boring was counted about one year later than the lower half, and in the interim I gained experience that made the separation of additional pollen types possible. Thus the presence in the upper part of the diagram of a pollen type that is absent in the lower part may mean only that the type was misidentified in the lower part of the core, not that it was absent from the samples counted earlier.

In spite of these uncertainties, the presence of certain pollen grains in the counts demands consideration. One group of such grains includes pollen of plants whose presence in the area seems unlikely for phytogeographical reasons. The scattered finds of Ephedra pollen belong in this category. Since Andersen's (1954) report of Ephedra pollen in late-glacial sediments in Michigan, this distinctive grain has appeared in a number of spectra of widely different strati-

graphic position in midwestern North America. Maher (1962) summarized these finds and concluded that they result not from the presence of Ephedra in the Midwest but from long-distance transport of its pollen from its native range in the southwestern United States. At Cedar Bog Lake, Ephedra pollen grains (a total of seven) were found in all zones except the lowest. Even if Ephedra had become established in the area, it is highly unlikely that it could have persisted throughout the period represented by the pollen occurrences. The hypothesis of long-distance transport for Ephedra pollen is strengthened by the find of a grain of Prosopis cf. pubescens Benth. (screwbean mesquite), a southwestern associate of Ephedra whose presence in Minnesota during the time of the Quercus-Betula zone, in which the grain was found, is equally unlikely. If Maher's hypothesis that long-distance transport of pollen from the Southwest is favored by special meteorological conditions is correct, the fact that the grain of Prosopis was found in the same sample as an Ephedra grain may not be entirely coincidental.

Pollen of Sarcobatus vermiculatus (Hook.) Torr. (greasewood), a shrub whose present range extends no farther east than western North and South Dakota, belongs in the same category of far-blown pollen. So does Iva ciliata-type pollen, which derives from plants whose present range centers about the Gulf coast and extends no farther north than Iowa. Similarly, the presence of pollen of Tsuga (eastern hemlock), which at present scarcely extends west of Wisconsin, or of Morus rubra (red mulberry), which extends northward only into southeastern Minnesota today, or of Platanus occidentalis (American sycamore), which fails to reach Minnesota from the south, cannot be taken as indisputable evidence that these trees ever grew near Cedar Bog Lake.

The interpretation of most of the rest of the pollen types that occur sporadically in small percentages must remain in doubt. Only if the percentages of such a type rise significantly in one stratigraphic interval against a nearly constant background of percentages of other types--as do those of Tilia, for example, in the Tilia subzone--can the inference that the plant occurred nearby be made safely.

Comparison with other diagrams

Artist (1939) presented a pollen diagram of Cedar Creek Bog together with diagrams from a number of other sites on the Anoka Sand Plain. The location of his boring in the bog is unknown, but the boring was relatively deep; he penetrated 11 meters of sediment without reaching the substratum. Although Artist's published diagram is a generalized one showing only the curves for the most abundant tree pollen types, he presents his counts of other pollen types in table form. When these are plotted in standard form, the resulting diagram (fig. 6) resembles the present one remarkably. The only change here made in Artist's original data is the combination of his counts for Picea and Abies; as was true of much early pollen analysis in this country, Artist's counts of Abies were much too high because of morphological confusion of Picea and Abies pollen (Potzger, 1944).

The Picea-Larix and the Pinus-Pteridium zones show up distinctly in Artist's diagram (fig. 6, analyses at 10 and 11 m and a single analysis at 9 m, respectively), including the maximum of Betula that comes between them. The Compositae-Quercus zone includes his analyses from 8 to 3 meters, and within it the Ulmus subzone (7 and 8 m) and Tilia subzone (3, 4, and 5 m) are distinguishable. The top of

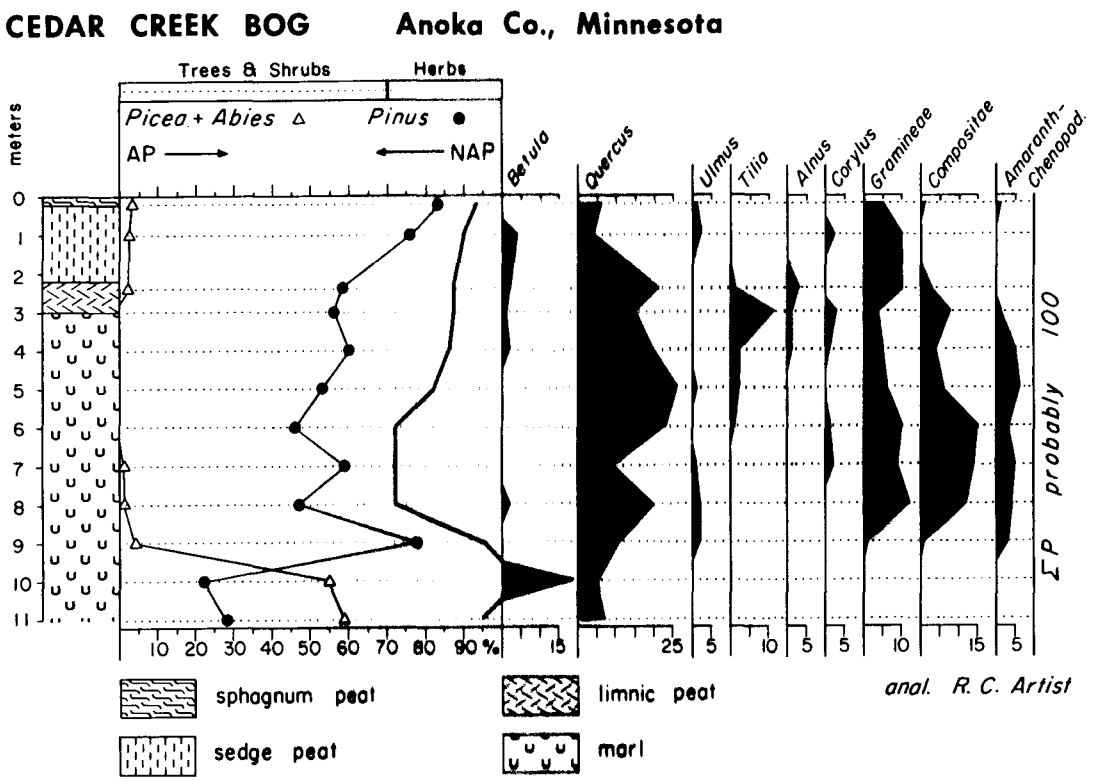


Figure 6. Pollen diagram of Cedar Creek Bog. Redrawn from data from Artist (1939).

the Compositae-Quercus zone roughly corresponds with the cessation of marl deposition in Artist's core, as it does in mine.

The differences between Artist's diagram and mine are largely unexplained, especially his consistently higher values of Pinus pollen. Several explanations for the difference are possible: 1) local over-representation of pine at the site of Artist's boring, although this surely could not be true throughout his diagram, especially since much of it is in lake sediments; 2) Artist may have counted every fragment of Pinus pollen as one grain, although this factor alone is probably insufficient to account for the differences; 3) Artist's counts may have been made at low magnification or of slides with too great a concentration of pollen and debris--in this case many smaller grains might have been overlooked as the easily-visible pine grains were counted; 4) differences in the technique of preparing and mounting the sediment for counting.

Pollen counts of samples of one complete core and part of another core of Cedar Bog Lake were made by Lindeman and published by Flint and Deevey (1951). The diagrams are difficult to compare in detail with the present one, since non-arboreal pollen was not recorded. The major zones shown agree in the two diagrams, however. Thus the A zone of Lindeman's diagram, with its high "Abies" (= Picea), is the Picea-Larix zone, the B zone corresponds to the Pinus-Pteridium zone, and the C1 zone is roughly equivalent to the Ulmus subzone of the Compositae-Quercus zone. Even the C3 zone, judged by the trend of his Alnus curve, must correspond approximately to the Quercus-Betula zone.

The other pollen diagrams from the Anoka Sand Plain by Artist (1939) and Wilson and Potzger (1943) can similarly be matched in their

broad features to the Cedar Bog Lake diagram. The Picea-Larix and Pinus-Pteridium zones can readily be recognized in the older diagrams by their high values of Picea and Pinus pollen, respectively, and the Ulmus subzone of the Compositae-Quercus zone is usually prominent as well. If the counts include non-arboreal pollen--or even, as in Wilson and Potzger's case, only Gramineae pollen--the top of the Compositae-Quercus zone can be picked out, and an increase in Betula pollen in the upper part of the diagrams is a general phenomenon, even though the ecological significance of the increase remains in doubt.

The greatest similarity to the present Cedar Bog Lake diagram, however, is to be found in the diagrams from Lake Carlson and Kirchner Marsh in Dakota County, by Patten (1959) and Winter (1961, 1962) respectively. In spite of the distance and the topographic and edaphic differences between the Anoka Sand Plain and the St. Croix Moraine, the present vegetation of the two areas is rather similar, although the maple-basswood "Big Woods" (Daubenmire, 1936) is much closer to the latter. The pollen diagrams suggest that the similarity of vegetation extended into the past, as well. The two Dakota County diagrams have been compared in detail by Wright, Winter, and Patten (1962). Figure 7 indicates how the zones they define correspond to the Cedar Bog Lake pollen zones.

Correlation with other diagrams

Three radiocarbon dates have been obtained from the core used for pollen analysis or from cores adjacent to it; correlation of the cores was by sediment lithology. The dates, determined at the Yale laboratory, are shown on the pollen diagram, figure 3, and in figure 7.

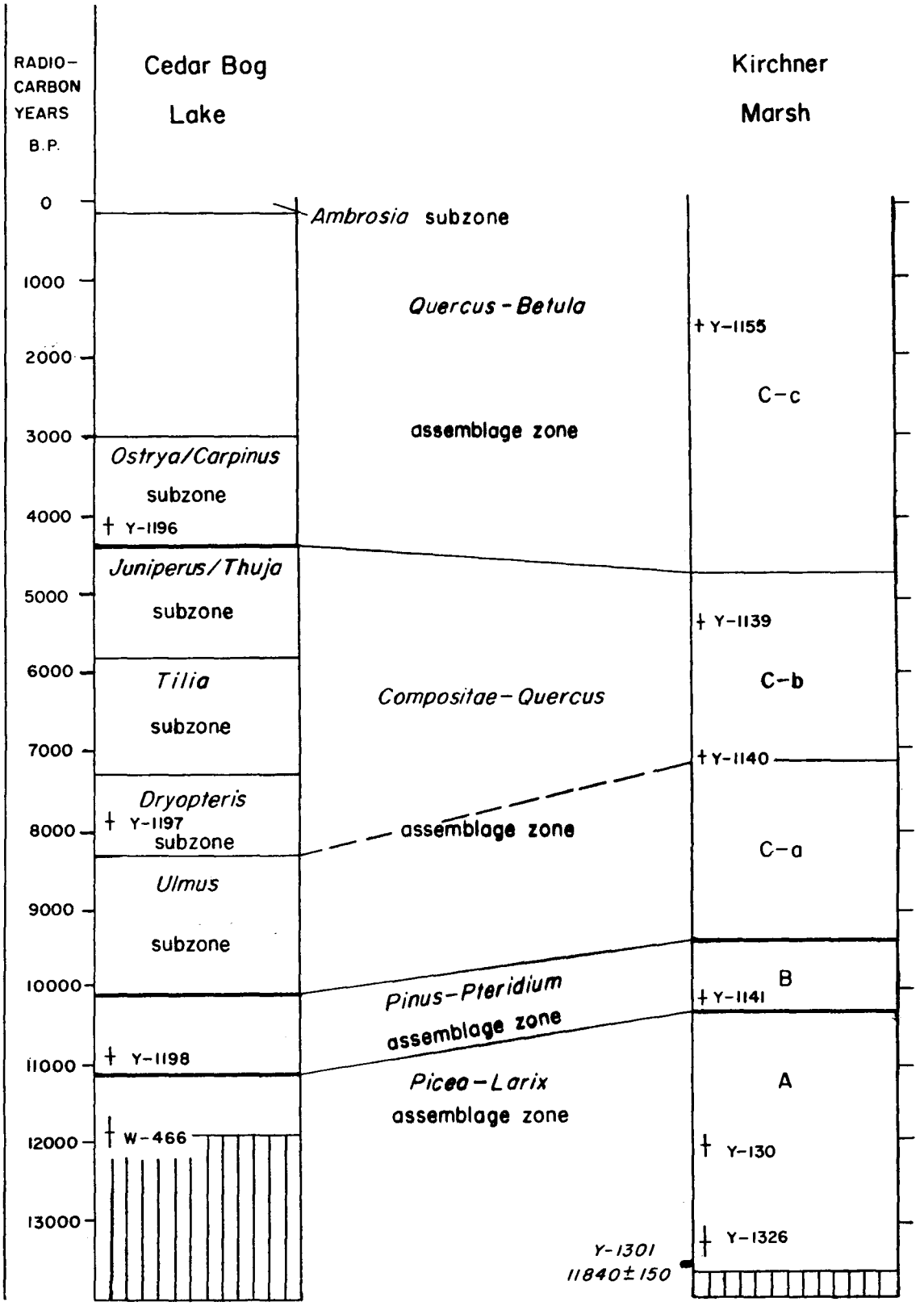


Figure 7. Correlation of pollen zones at Cedar Bog Lake and Kirchner Marsh. Radiocarbon dates are shown by crosses; the vertical line indicates the reported standard error. Anomalous date is given in italics at its proper stratigraphic position. Pollen zones at Kirchner Marsh according to Winter (1962).

Two other dates from Cedar Bog Lake have been reported. A date of 11,830 ± 200 years BP (W-466, Rubin and Alexander, 1958; Wright and Rubin, 1956) was obtained from a sample of the basal organic sediment at a depth of 30 feet at the west margin of the lake. Since the assumption that the lowermost organic sediment in at least the deeper parts of the lake basin was deposited synchronously is reasonable, this date may be applied with caution to the lowest organic sediment in the pollen core, at 1620 cm. The other date is of sediment collected by M. F. Buell at the site of Lindeman's profile 4 (Flint and Deevey, 1951), which places it near the top of zone B (Pinus-Pteridium zone) in Lindeman's diagram. The date, 7,988 ± 420 years BP (C-332, Arnold and Libby, 1951), is much too young in comparison with the date of 10,840 ± 160 years BP obtained for the same pollen zone in the present study. The reason for the discrepancy is unknown, and the former date is here rejected.

The correlation of the pollen zones at Cedar Bog Lake and Kirchner Marsh, at which several radiocarbon dates are also available, is indicated in figure 7. The zone boundaries shown were placed by linear interpolation on graphs of sediment depth plotted against radiocarbon age. The correlation of the Picea-Larix and Pinus-Pteridium zones will be discussed later. Here it is of interest to note the difference in radiocarbon age of the Compositae-Quercus zone at Cedar Bog Lake and Kirchner Marsh. The available dates suggest that the Compositae-Quercus zone, recording the invasion of pine-hardwood forest by prairie, began more than 500 years earlier at Cedar Bog Lake, and that the culmination of the invasion--marked by the top of the Ulmus subzone--also occurred at least that much earlier at Cedar Bog Lake than at Kirchner Marsh. Furthermore, the end of the prairie invasion, as

indicated by the top of the Compositae-Quercus zone, appears to have been about 500 years later at Cedar Bog Lake than at Kirchner Marsh.

It is not surprising, perhaps, that the top of the Ulmus subzone is not the same age in different regions, since at least at Cedar Bog Lake it is succeeded by a subzone (the Dryopteris subzone) whose vegetation and climatic implications are largely local. The suggestion that the interval when prairie vegetation was important began earlier and lasted longer at the more northern site, however, is of greater interest. The validity of both the pollen stratigraphy and the radiocarbon determinations should be checked at other sites in each of the two areas. A close comparison of the upper boundary of the Compositae-Quercus zone at Cedar Bog Lake and Kirchner Marsh is especially difficult, as fluctuations in the local pollen rain may mask the regional changes on which tracing of the zone boundary depends. If the suggested zone equivalence and the dating of the zone boundaries are correct, a suggested explanation for the greater length of the zone at Cedar Bog Lake is that the climatic changes presumably recorded by the zone boundaries were sufficiently gradual to permit local environmental factors, such as the edaphic or topographic differences between the two sites, to control the succession of plant communities.

REDEPOSITED POLLEN IN LATE-WISCONSIN POLLEN SPECTRA FROM EAST-CENTRAL MINNESOTA

The possibility that some of the pollen contained in Pleistocene mineral-rich sediments may be secondarily derived from older deposits has been considered by pollen stratigraphers since Iversen (1936) clearly pointed out the danger. The fact that at only a few sites (Iversen, 1936, 1942, 1947; Krog, 1954) has secondary pollen been identified, its source demonstrated, and its masking effect on the pollen spectra objectively removed, however, attests to the difficulties in recognition and treatment of the problem. In mid-continental North America, the hypothesis of secondary redeposition has been invoked several times (Andersen, 1954; Martin, 1958b; Frey, 1959) to explain the apparently anomalous association of pollen of deciduous hardwoods with that of boreal elements in the same spectra. No direct evidence has been given, however, and Davis (1961a) has urged a more critical testing of the hypothesis.

In east-central Minnesota, the surface drift is a gray till or its stratified-drift facies that is rich in fragments of Cretaceous shale, sandstone, and lignite, like those rocks that underlie the drift in much of the western and southwestern portions of the state. As shown by Pierce (1961), the Cretaceous rocks contain a variety of pollen and spores, and some of these are indistinguishable from pollen of living plants (Pierce, 1957). When preliminary analysis of the unweathered gray till revealed that it contained some of the same Cretaceous pollen and spore types, it was realized that late-Wisconsin lacustrine sediments derived in part from the gray till might well be contaminated by secondary pollen. Andree Bog, a site in Isanti County, proved to contain such sediments.

Redeposited pollen at Andree Bog

Location and description of site.

Andree Bog lies in sections 5 and 6, T. 37 N., R. 23 W., Isanti County, Minnesota, just south of the Kanabec County line and west of the hamlet of Andree (Fig. 1). A shallow, irregular peat deposit that covers nearly one square mile, it lies in an area of gently rolling topography mantled with calcareous silt and clay, on which soils of the Dalbo-Brickton association have developed (Farnham and others, 1958). Most of the bog surface at present is covered by a sedge meadow or shrub-carr community (in the sense of Curtis, 1959); grasses and sedges dominate the vegetation, with Carex sp. most common. Local areas are dominated by Typha latifolia, Phragmites communis, or Calamagrostis canadensis. Low shrubs are scattered over the bog, including Salix sp., Cornus stolonifera, and Betula pumila var. glandulifera. At the north side of the bog is a stand of large Larix laricina, and the cut and burned stumps present over much of the rest of the bog are evidence that the tamarack forest was at one time more extensive. Small islands of mineral soil occur within the bog; these support a dense growth of Populus tremuloides, Quercus macrocarpa, Betula papyrifera, and Corylus americana, with much evidence of disturbance by fire.

The upland vegetation in the area of Dalbo-Brickton soils surrounding the bog includes outliers of the maple-basswood Big Woods community of Daubenmire (1936). A fine undisturbed stand of this community occurs about two miles north of Andree Bog. Tilia americana is dominant in most of the stand, and Acer saccharum and Quercus rubra var. borealis are its common associates. Fraxinus nigra, Betula papyrifera, Ostrya virginiana, Ulmus americana, Populus tremuloides,

Populus grandidentata, and Carya cordiformis share the canopy, and a few large individuals of Quercus macrocarpa and Pinus strobus are scattered throughout the stand. The understory is rich and includes Ostrya virginiana, Carpinus caroliniana, Acer saccharum, Fraxinus nigra, Fraxinus pennsylvanica, Prunus virginiana, Xanthoxylum americanum, Corylus americana, Ilex verticillata, Rhamnus alnifolia, Cornus sp., and Viburnum sp.

Andree Bog was chosen as a site for pollen analysis because it rests upon the sediments of Lake Grantsburg. This glacial lake formed at the north edge of the Grantsburg sublobe when, at its maximum advance, that body of ice interrupted the normal south and southeast drainage of the area (Cooper, 1935). The advance of the Grantsburg sublobe and the formation of Lake Grantsburg are events of the Mankato stade (Wright and Rubin, 1956). When the Grantsburg sublobe began to disintegrate, Lake Grantsburg quickly drained and the Anoka Sand Plain began to form. It was hoped that the sediments of Andree Bog might contain a continuous pollen record of the vegetation in the area immediately following the drainage of Lake Grantsburg, a record that would thus predate the lowest pollen stratigraphy available in lakes on the Anoka Sand Plain.

Sediment stratigraphy.

The core used for pollen analysis contains the thickest sequence of organic deposits found in a series of probings and trial borings on a north-south transect across Andree Bog. The core was taken about 180 meters from the present south edge of the bog. A description of the sediments follows; depths are given from the bog surface.

0 - 180 cm: Peat. Th^0 3, Tb^0 1, Tl +, Dg +; medium brown, very firm, elas 3, calc 0. Lower contact gradational over 5 cm.

180 - 292 cm: Peaty coarse-detritus copropel. Ld^0 1, Th^0 1, Dg 1, Dh 1; dark brown, very firm, elas 2, calc 0. Lower contact sharp.

292 - 320 cm: Coarse-detritus copropel. Ld^0 1, Dg 2, Dh 1, [test. moll. +]; very dark gray-brown, very firm, elas 2, calc 1. Lower contact gradational over 10 cm.

320 - 414 cm: Marly fine-detritus copropel. Ld^0 2, Lc 1, Dg 1, Dh +, [test. moll. 2]; medium olive, very firm, elas 3, calc 4. Lower contact sharp.

414 - 427 cm: Humified fine-detritus copropel. Ld^2 2, Dg 2; very dark brown, very firm, elas 3, calc 0. Najas seeds common. Microscopic estimate (after HF treatment): pyrite very rare, cellular fragments common, hyphae very rare, pollen infrequent, algae abundant (Tetraedron, Scenedesmus, Pediastrum, Botryococcus, others), chitin common, charcoal infrequent. Lower contact sharp.

427 - 460 cm: Marly copropel. Ld^0 2, Lc 2, Dg +, test. moll. 4 ; medium olive, very firm, elas 3, calc 3. Microscopic estimate (after HF treatment): pyrite very rare, cellular fragments common, hyphae very rare, pollen common, algae abundant (Pediastrum, Scenedesmus, Botryococcus), chitin infrequent, charcoal rare. Lower contact sharp.

460 - 575 cm: Copropel (Scenedesmus-gyttja). Ld^0 4; medium olive-gray, very firm, elas 4, calc 0. Microscopic estimate (after HF treatment): pyrite very rare to common, cellular fragments common, hyphae very rare, pollen common, algae very abundant (Scenedesmus, Pediastrum, Botryococcus, Tetraedron, Coelastrum, others), chitin infrequent, charcoal rare. Lower contact gradational over 1 cm.

575 - 581 cm: Silty copropel. Ld^0 2, Ag 2; medium olive-gray, very firm, elas 3, calc 0. Microscopic estimate (after HF treatment): pyrite infrequent, cellular fragments common, hyphae common, pollen common, algae rare (Pediastrum, Scenedesmus, Botryococcus), chitin infrequent, charcoal rare. Lower contact gradational over 1 cm.

581 - 591 cm: Copropelic silt. Ag 3, Ld^0 1, Dl +, Dh +; medium gray, very firm, elas 2, calc 2. Inclusions and laminae of Dg 2, Ag 1, Ld^0 1. Microscopic estimate (after HF treatment): pyrite infrequent, cellular fragments common, hyphae common, pollen infrequent, algae rare (Pediastrum, Botryococcus), chitin rare, charcoal rare. Lower contact sharp.

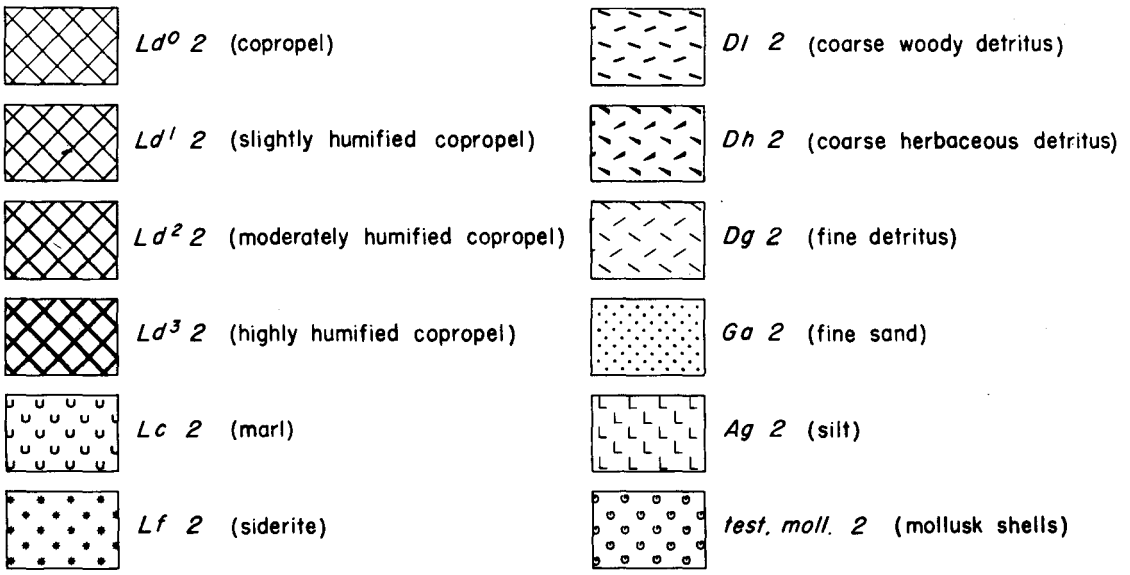
591 - 618 cm: Silt interlaminated with detritus. Ag 4, Ld^0 +, Dl +, Dh +; medium gray, very firm, elas 2, calc 2. Laminae of Dg 3, Dl 1, Dh +, dark brown, at 591, 593.5, 594.5, 597.5, 599-602, 605, 606, 607.5-609, and 616 cm. Microscopic estimate (after HF treatment): pyrite infrequent, cellular fragments abundant, hyphae common, pollen rare, algae very rare (Pediastrum, Botryococcus), chitin rare, charcoal common. Lower contact gradational over 1 cm.

618 - 940+ cm: Silt. Ag 4; light gray, very firm, elas 0, calc 3. In places interbedded and interlaminated with medium gray clay (As 4). Microscopic estimate (after HF treatment): pyrite common, cellular fragments abundant, hyphae infrequent, pollen very rare, algae very rare (Pediastrum), chitin very rare, charcoal rare. Base not seen.

Pollen stratigraphy.

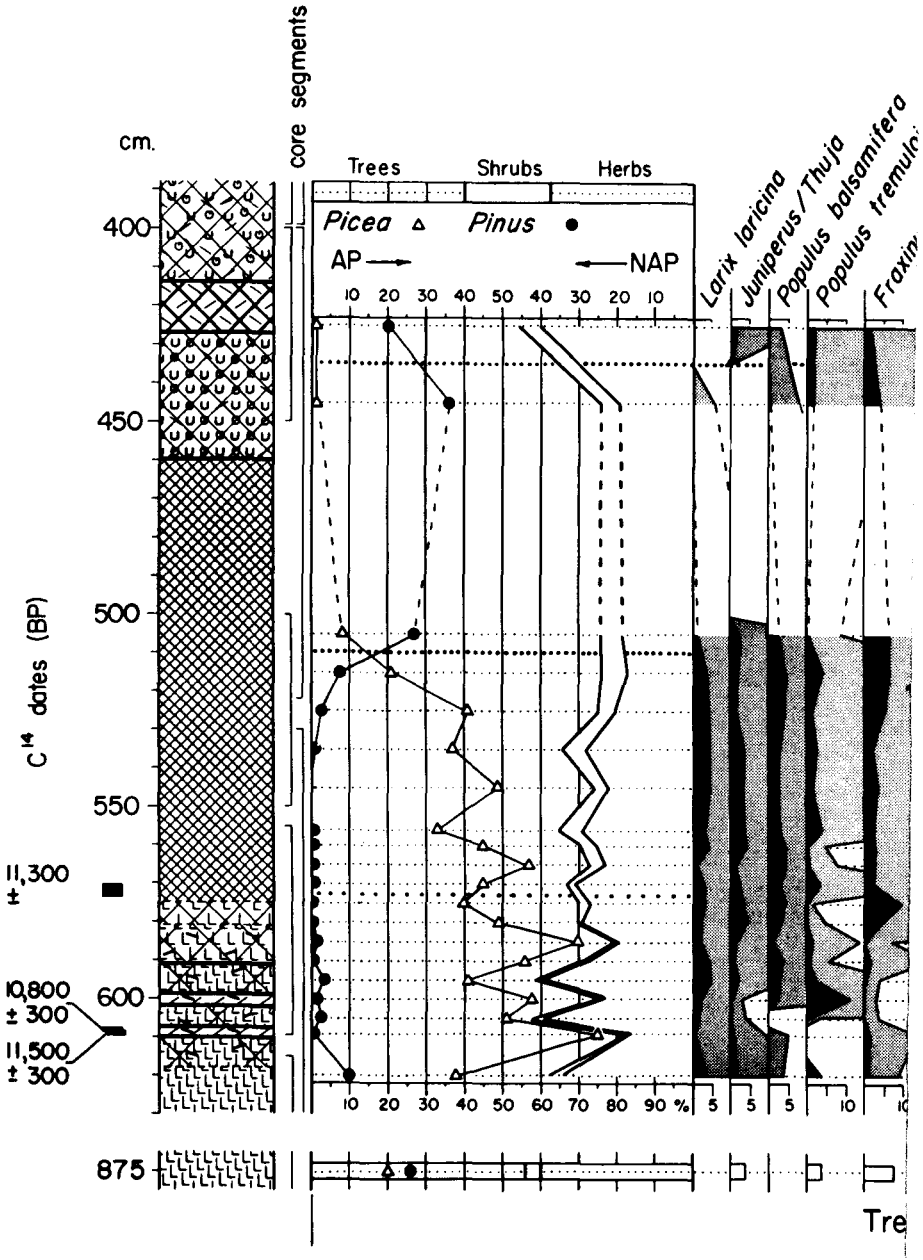
The pollen diagram from the basal sediments of Andree Bog (fig. 8) may be divided into pollen zones that correspond with those defined at Cedar Bog Lake and Horseshoe Lake, sites lying about 20 miles to the south on the Anoka Sand Plain. The lower part of the diagram is dominated by Picea pollen and is clearly referable to the

F i g u r e 8 . Pollen diagram of Andree Bog. Scale at base of diagram gives percentages for black silhouettes; stippled silhouettes are exaggerated 10X scale. Abbreviations: AP = arboreal pollen, NAP = non-arboreal pollen, undiff. = undifferentiated, Indet. = indeterminable, Sph. = Sphagnum, Unk. = unknown, pre-Q = pre-Quaternary microfossils. Symbols used in the sediment lithology column are given below.

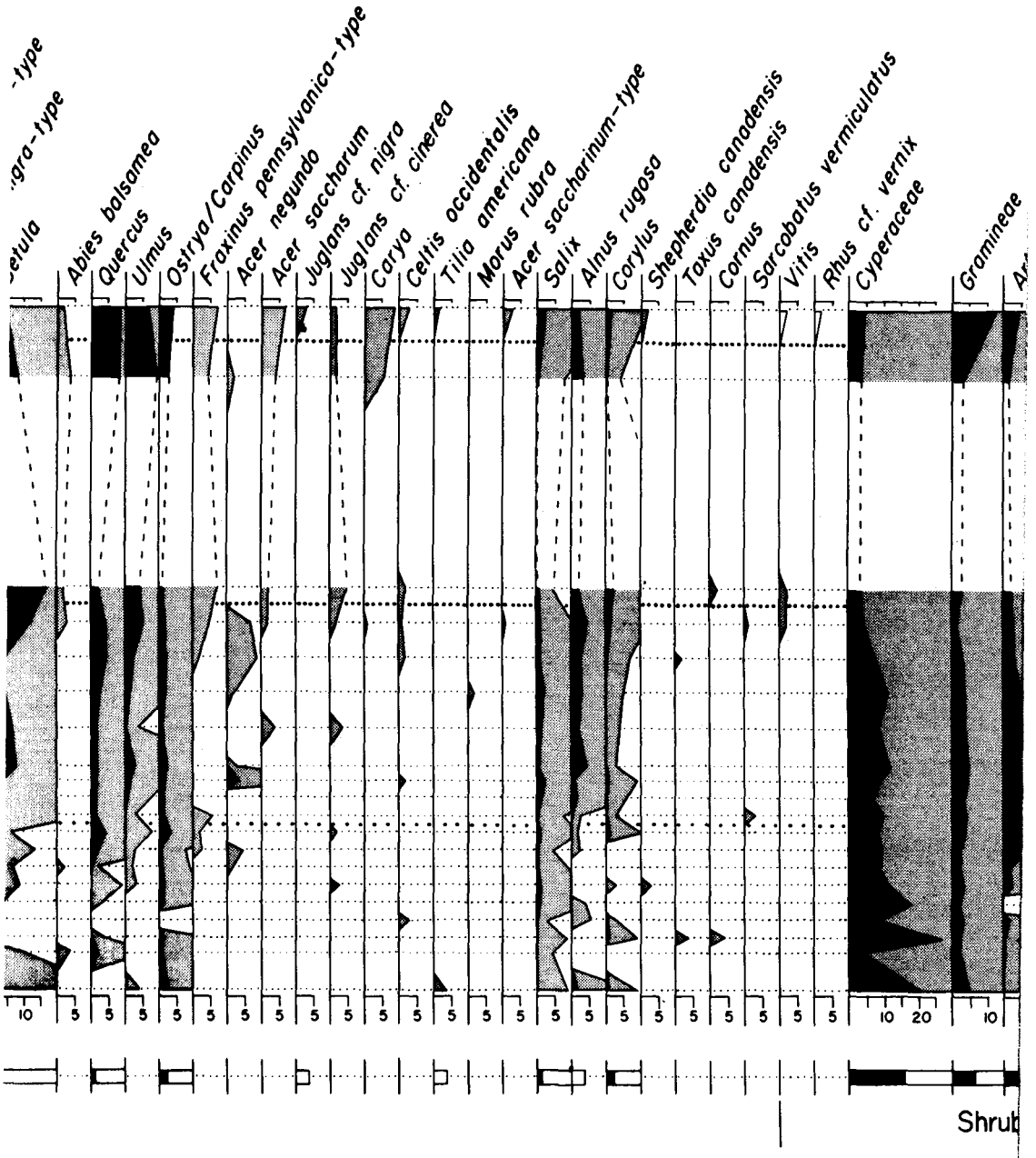


Density of symbols indicates proportion of component in the sediment. Density shown here indicates a proportion of 50%.

ANDREE BOG Isanti Co.,



Minnesota


-type
igra-type
etula
Abies balsamea
Quercus
Ulmus
Ostrya/Carpinus
Fraxinus pennsylvanica-type
Acer negundo
Acer saccharum
Juglans cf. nigra
Juglans cf. cinerea
Carya
Celtis occidentalis
Tilia americana
Morus rubra
Acer saccharinum-type
Salix
Alnus rugosa
Corylus
Shepherdia canadensis
Taxus canadensis
Cornus
Sarcobatus vermiculatus
Vitis
Rhus cf. vernix
Cyperaceae
Gramineae
10
5
5
5
5
5
5
5
5
5
5
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5
5
5
5
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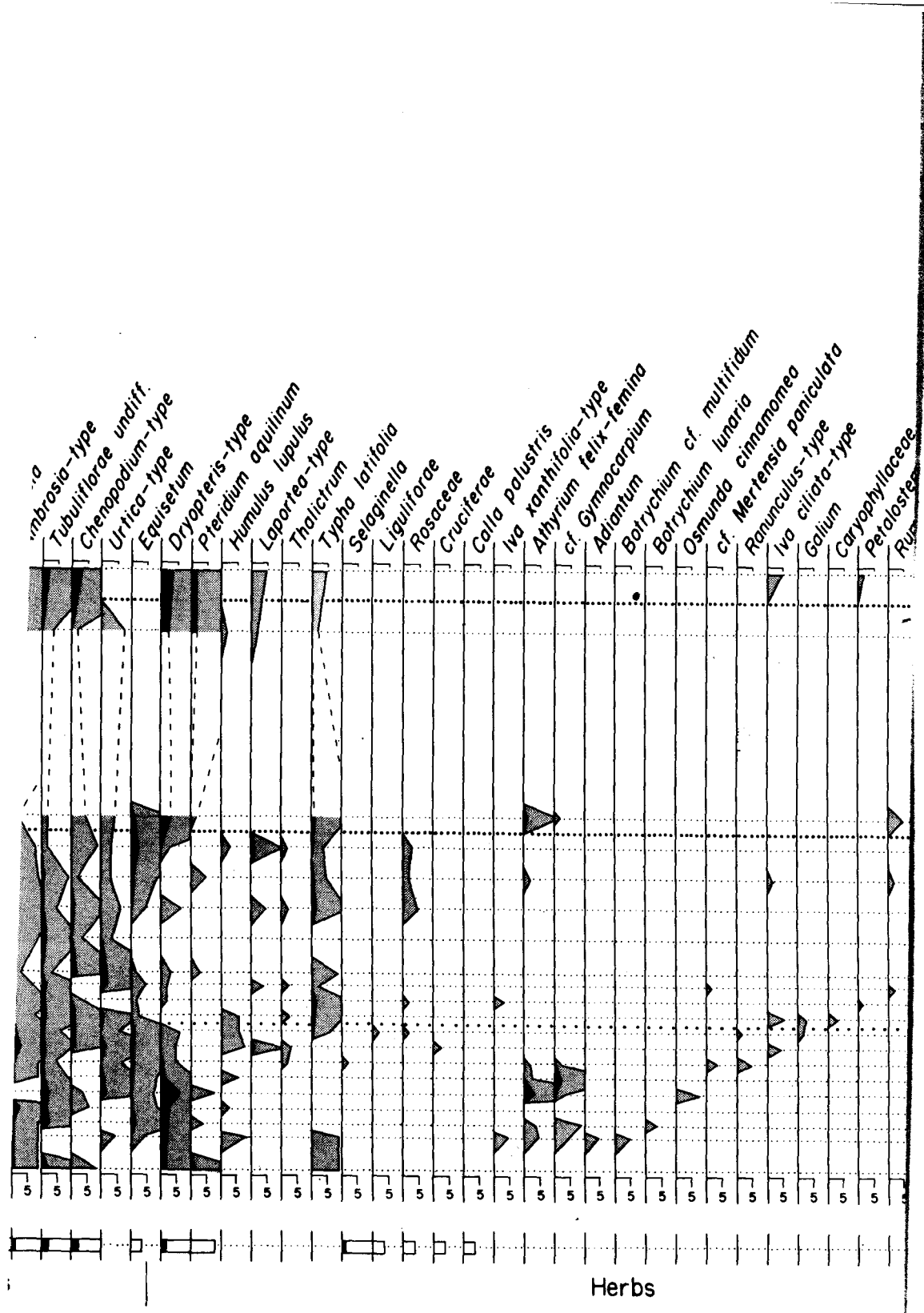
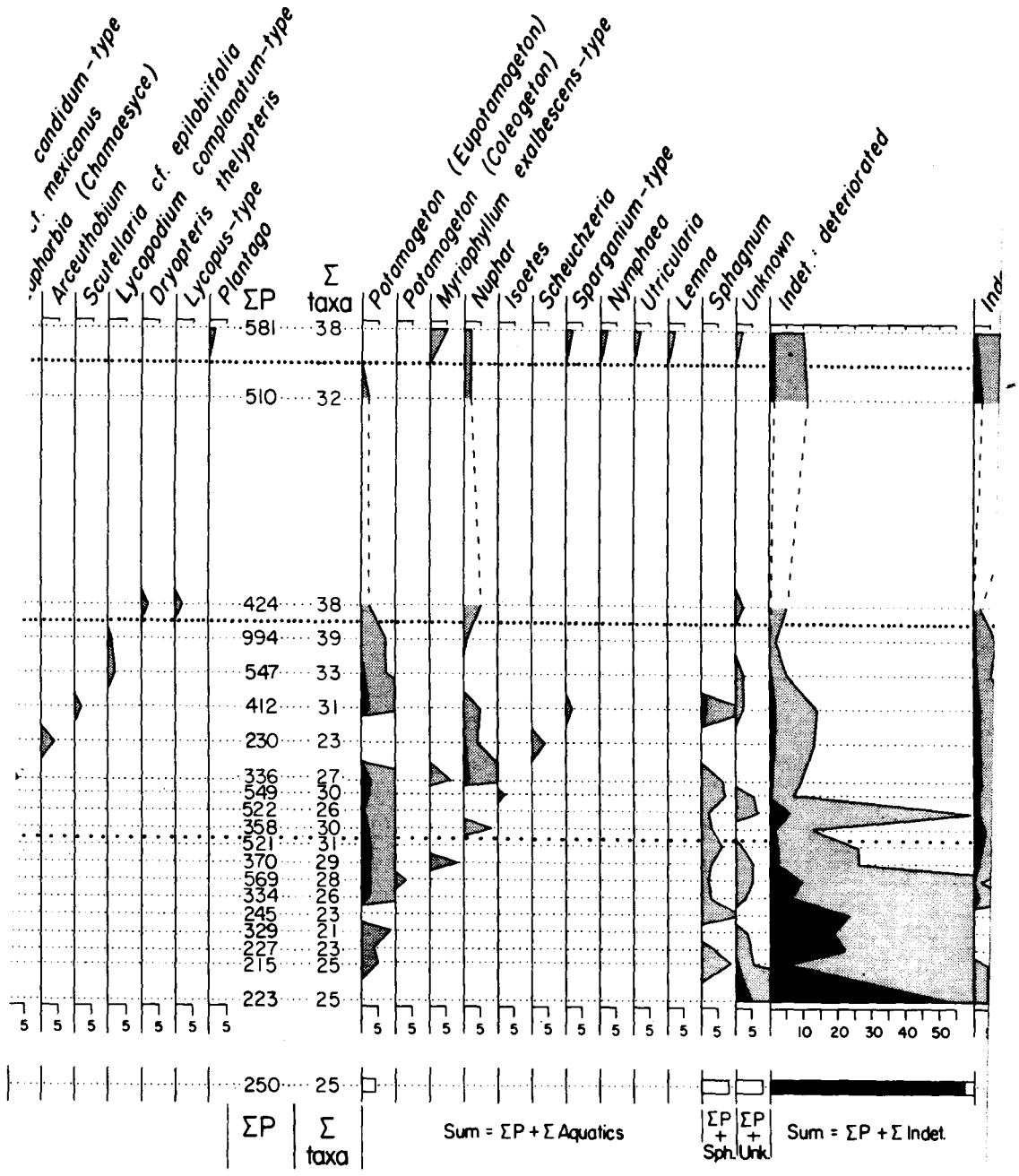
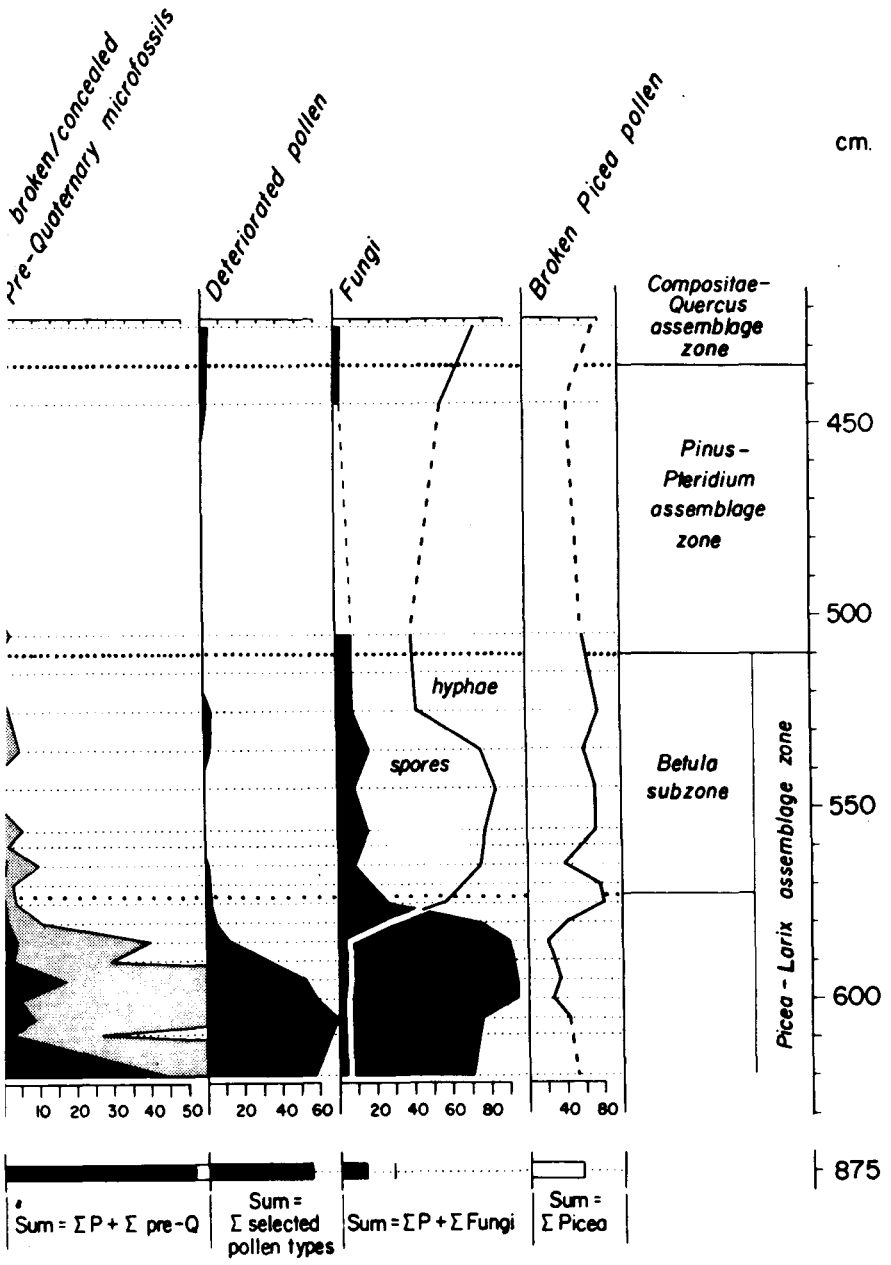
5
10
20
10
Shrub


Ambrosia-type
Tubuliflorae undiff.
Chenopodium-type
Urtica-type
Equisetum
Dryopteris-type
Pteridium aquilinum
Humulus lupulus
Laportea-type
Thalictrum
Typha latifolia
Selaginella
Liguliflorae
Rosaceae
Cruciferae
Calla palustris
Iva xanthifolia-type
Athyrium felix-femina
cf. Gymnocarpium
Adiantum
Botrychium cf. multifidum
Botrychium lunaria
Osmunda cinnamomea
cf. Mertensia paniculata
Ranunculus-type
Iva ciliata-type
Galium
Caryophyllaceae
Petalostes
5
Herbs


cf. candidum-type
Euphorbia mexicanus
Arceuthobium (Chamaesyce)
Scutellaria c.f. epilobiifolia
Lycopodium complanatum-type
Dryopteris thelypteris
Lycopus-type
Plantago
ΣP
Σ taxa
Potamogeton (Eupotamogeton)
Potamogeton (Coleogeton)
Myriophyllum exalbescens-type
Nuphar
Isoetes
Scheuchzeria
Sparganium-type
Nymphaea
Utricularia
Lemna
Sphagnum
Unknown
Indet.: deteriorated
581 38
510 32
424 38
994 39
547 33
412 31
230 23
336 27
549 30
522 26
358 30
521 31
370 29
569 28
334 26
245 23
329 21
227 23
215 25
223 25
250 25
5
10 20 30 40 50
ΣP
Σ taxa
Sum = ΣP + Σ Aquatics
ΣP + Sph.
ΣP + Unk.
Sum = ΣP + Σ Indet.



anal. E. J. Cushing, 1962

Picea-Larix assemblage zone. Within the zone only the Betula subzone is recognized; its development at Andree Bog is exactly similar to its definition at Horseshoe Lake. The Pinus-Pteridium assemblage zone is present but not well shown in the diagram because of an interruption in the pollen core (the sediment stratigraphy given is taken from an adjacent core segment that covers the missing interval in the pollen core). The sharp rise in relative frequency of pollen of Artemisia, Gramineae, and Chenopodium-type in the uppermost spectrum shown in the diagram marks the base of the Compositae-Quercus assemblage zone.

Of particular interest in the interpretation of the pollen diagram is the occurrence in the Picea-Larix zone of pollen of Fraxinus, Quercus, Ulmus, Ostrya/Carpinus, Acer, Juglans, Celtis, Tilia, Morus, and Vitis. These are types that might be considered to be secondarily redeposited, following the interpretation of Andersen (1954).

Secondary microfossils.

In addition to the pollen grains of deciduous trees, which might or might not be suspected of being secondary, pollen and spores of undoubted Cretaceous age were present in the lowest spectra analysed. Many of the types described by Pierce (1961) from Cretaceous rocks in Minnesota were identified by comparison with Pierce's type slides. In all, 16 different types of spores and pollen could be definitely identified with known described genera or species from Cretaceous rocks, 12 were referred to described pre-Quaternary taxa, and five types are unknown from either present or described fossil taxa; table 4 (appendix) lists the various types.

Dinoflagellates, hystrichosphaerids, and a variety of other peculiar microfossils were also present in the samples that contained

Cretaceous pollen and spores. Photomicrographs of some of these microfossils were sent to Joan B. Stough, who kindly suggested the following tentative identifications: Family Hystrichosphaeridae: Hystrichosphaera sp., cf. H. furcata (Ehrenberg) Wetzel, H. ramosa Wetzel, Hystrichosphaeridium ramuliferum Deflandre, H. membranaceum Philippet, Baltisphaeridium cf. fimbriatum (White) Eisenack, B. cf. pilosum (Ehrenberg) Sarjeant, cf. B. varispinosum Sarjeant; Family Pterospermopsidae: Cymatiosphaera sp. The age of most of these species ranges from Jurassic to Tertiary, and Miss Stough (personal communication) considers a Cretaceous age for the assemblage highly probable. The dinoflagellates have not been identified, but most of them are clearly unlike any extant fresh-water species figured, for example, by Eddy (1930). Their close association with hystrichosphaerids of undoubted pre-Quaternary age, and their absence in sediments where other Cretaceous microfossils are absent, is presumptive evidence that the dinoflagellates encountered are secondarily derived and did not live in the lake waters at the site--a possibility recently raised by Churchill and Sarjeant (1962). The same argument could be applied to a wide variety of other microfossils that were present in the secondarily contaminated samples, but because few of these could be identified they were not systematically counted.

The sum of pre-Quaternary pollen, spores, hystrichosphaerids, and dinoflagellates is expressed as a percentage of the pollen sum plus these pre-Quaternary microfossils in the pollen diagram, figure 8. It is immediately clear from the curve that the bulk of the secondary redeposition is confined to the lowest spectra of the diagram.

At least three meters of lake silt and clay lie beneath the lowest trace of macroscopic organic matter in the pollen core at

Andree Bog. This silt and clay was probably deposited rapidly in the proglacial Lake Grantsburg and therefore probably contains little primary pollen--that is, pollen and spores derived from plants living at the time of deposition of the sediment. The pollen content of a sample of this sediment might therefore be used to give a representative sample of the secondary pollen transported and deposited with the mineral grains. To this end, a sample of silt from 875 cm, 2.5 m below the lowest spectrum of the main diagram, was analysed; its spectrum is shown at the bottom of the diagram (fig. 8).

To test the assumption that the spectrum at 875 cm consists of largely secondary pollen, a sample of the till from which the lake silt was derived was analysed. The sample was of unoxidized gray silty till from a deep excavation near Elk River, about 30 miles southwest of Andree Bog. Nearly all of the pollen, spore, and microfossil types present in the glacial lake silt are also present in the till sample (table 4, appendix). Two other unoxidized samples of the gray silty till deposited by the Grantsburg sublobe have been examined: one from Minneapolis, about 50 miles south of Andree Bog, and the second from Rock Creek, about 12 miles to the east. Although quantitative analyses were not made, the microfossil content of these is similar qualitatively to the till sample from Elk River.

The microfossil content of the till from Elk River is compared with the analyses of the lake silt at 875 cm and the lowest spectrum (at 620 cm) of the Andree Bog diagram in figure 9. The three spectra are clearly similar. The agreement of the till spectrum with that from the lake silt (875 cm) supports the assumption that essentially all of the pollen in the silt is secondary. The greatest difference between the two spectra is the relatively higher frequency of

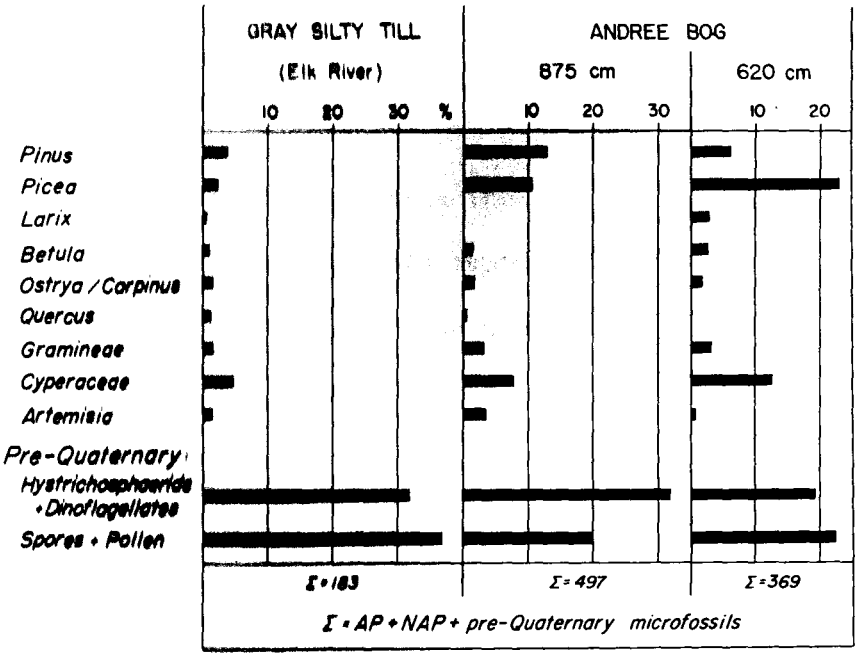


Figure 9. Microfossil content of gray silty till and two samples from Andree Bog. Only selected pollen types are shown.

Pinus and Picea pollen in the silt. A possible explanation is that some sorting of the pollen accompanied the sorting of the mineral particles derived from the unsorted till, and the relatively large conifer pollen grains (size 60-100 μ) were concentrated in the silt fraction. The same process could explain the higher ratio of hystrichosphaerids plus dinoflagellates (the bulk of which are in the same size range as conifer pollen) to pre-Quaternary pollen and spores in the silt.

Either the till spectrum or the silt spectrum could be used as the basis for quantitative subtraction of the secondary pollen from the higher spectra at Andree Bog; the spectrum from the silt at 875 cm is preferred here because it is probably more representative of the influx of secondary pollen at the site than the distant till sample. A visual comparison of the spectra at 875 and 620 cm in figure 9 suggests immediately that not all of the pollen at the latter level is secondary, that a part of the pollen of Picea, Larix, and Cyperaceae is clearly primary, and that all the pollen of Pinus, Ostrya/Carpinus, Gramineae, and Artemisia is probably secondary.

Because the content of identifiable pre-Quaternary microfossils in the secondary pollen sum is high (about 50 percent), it is possible to apply the quantitative subtraction method originated by Iversen (1936) to remove the effects of secondary redeposition from pollen spectra that contain both primary and secondary pollen. This was done by recalculating the percentages of the pollen types in each spectrum, taking the sum of pre-Quaternary microfossils in that spectrum as 100 percent. The recalculated value for each type in the spectrum at 875 cm was then subtracted from the recalculated value of the same type in the spectrum in question. The remainders in each spectrum, rounded to whole numbers, were then added to obtain a new sum on which the corrected relative frequencies could be based.

Only two spectra in the diagram (fig. 8), those at 595 and 620 cm, contain enough secondary pollen to make such a subtraction meaningful. The effect of the subtraction at the 620 cm level is to increase the relative frequency of Picea pollen from 38 to 57 percent, to increase Larix from 4 to 8 percent, and to change Cyperaceae from 21 to 25 percent. Juniperus/Thuja, Alnus, and Betula are present in minor amounts (3 percent each) after the subtraction, and all other pollen types are removed. Thus the high values of pollen types such as Pinus, Ostrya/Carpinus, Corylus, and Tubuliflorae in the lowest spectrum of the diagram are not to be interpreted as suggesting a change in the primary pollen rain.

Subtraction of the secondary pollen at 595 cm has less effect. Picea increases from 41 to 52 percent, Larix from 5 to 7 percent, and Cyperaceae from 18 to 22 percent. The small amounts of Pinus, Betula, and Quercus are removed, and the effect on the other curves is slight. At all other levels in the pollen diagram the effect of the subtraction of secondary pollen is negligible.

Pollen preservation and penecontemporaneous redeposition.

Although the results just given have a general validity, it is fruitless to try to make the subtraction of secondary pollen at Andree Bog more precise because of the high proportion of indeterminable pollen grains present in the contaminated spectra. Most of the indeterminable grains cannot be identified or characterized because they are deteriorated; as the curve for indeterminable: deteriorated in figure 8 shows, these may make up as much as 50 percent of all pollen and spores present. Deteriorated grains are especially characteristic of the samples containing secondary pollen; in the till sample examined 83 percent of the grains counted were indeterminable

because of deterioration. The curve for indeterminable: deteriorated thus predictably tends to parallel the curve for pre-Quaternary microfossils. Significant deviations from parallelism exist, however, at 600 and 605 cm.

Another index of pollen preservation is given by the curve for deteriorated pollen. This category includes grains that were identifiable but were damaged by either corrosion or degradation of the exine. The curve is similar to the "degree of destruction" curve used by Troels-Smith (1941) and Jørgensen (1954); in the Andree Bog diagram it is the sum of deteriorated pollen of Pinus, Picea, Alnus, Betula, Corylus, Ostrya/Carpinus, Quercus, Ulmus, Salix, Gramineae, Tubuliflorae, Ambrosia-type, Artemisia, and Chenopodium-type expressed as a percentage of the sum of all identified grains of the same types. Other pollen types are excluded because slight degrees of deterioration of their exines are difficult to recognize. The relative frequency of deteriorated but identifiable pollen is of course high in samples with a high percentage of indeterminable: deteriorated grains; indeed, where pollen preservation is very poor the separation of these two groups may become highly subjective. The deteriorated pollen curve, however, is not parallel in detail to either the indeterminable: deteriorated or the pre-Quaternary microfossils curves. The explanation lies in the inclusion of both corroded and degraded grains (as these terms are defined in the section on identifications, p. 40) in the curve of deteriorated grains. Although these two types of deteriorated grains were not systematically separated during the counting, it was observed that the ratio of corroded to degraded grains varied markedly. In the samples with a high content of secondary microfossils, including the till sample, deterioration is largely

attributable to degradation of the exine, and corrosion is rare. In other samples, notably at 600, 605, and 609 cm, corrosion is the dominant cause of deterioration, but because slight corrosion rarely makes grains indeterminable the number of indeterminable grains in the same samples can be low.

The kind and degree of pollen deterioration and the content of secondary microfossils is closely related to the lithology of the sediment in the core. The spectra at 600, 605, and 609 cm, which have a relatively low content of secondary microfossils and a relatively high ratio of corroded to degraded pollen, are from laminae of plant detritus containing little silt. The samples from relatively pure silt (at 595 and 620 cm), however, contain many secondary microfossils and a low ratio of corroded to degraded grains (and therefore high values for indeterminable: deteriorated grains). The lamina at 605 cm is less than one mm thick, and the pollen sample taken at that level included some of the adjacent silt; this fact reasonably explains the higher percentage of secondary microfossils in the sample. The laminae of plant detritus are similar in composition to the litter horizons discussed later. They contain twigs, needles, cone scales, seeds, microsporophylls, and microsporangia of Picea, Larix needles, other seeds (including Rubus sp., Potentilla sp., and Carex sp.), moss fragments, and abundant fungal rhizomorphs and mycelia. They are interpreted here as strata of plant litter washed into the lake basin from the surrounding slopes after the drainage of Lake Grantsburg. The pollen content of the litter horizons is thus a combination of pollen washed in with other plant detritus and that deposited directly from the pollen rain at the time of final deposition in the lake basin. The corrosion of much of the pollen presumably occurred while the grains were exposed to

the air in the surface litter before redeposition in the lake. Much of the pollen in the litter horizons is thus redeposited, but in contrast to the secondary pollen in the silt layers it was derived from plants living at or shortly before the time of deposition. To distinguish it from the secondary redeposited pollen, the rebedded pollen in the litter horizons may be called penecontemporaneous redeposited pollen.

Because fungal remains are an important constituent of the litter horizons, the abundance of fungal hyphae in the pollen slides may be used as an index of the penecontemporaneous redeposition. The frequency of fungal remains (spores plus hyphae fragments) expressed as a percentage of fungal remains plus the pollen sum is plotted as a curve in the diagram (fig. 8). Superimposed on the silhouette is a line that plots the ratio of fungal spores to hyphae in the samples. In the lower part of the diagram, where redeposited plant detritus is present, fungal remains are abundant and consist largely of hyphae fragments. Higher in the core (above 575 cm) the sediment is chiefly autochthonous, and there the fungal remains decline markedly in abundance and consist largely of wind-transported spores that were deposited directly with the pollen rain. Neither the silt at 875 cm nor the till sample analysed contains an appreciable quantity of fungal remains, so the abundance of hyphae fragments in the lower part of the core is traceable to the penecontemporaneous redeposition.

It must be stressed that the kind and degree of preservation alone can not at this site be used for separating secondary from primary pollen. Even in the till sample, where pollen preservation in general is very poor, perfectly preserved pollen grains and spores are not uncommon. These well-preserved grains include Cretaceous as well as

modern types. The cause of the degradation of the pollen exine is not understood, but it may be purely physical. If so, some grains within the till matrix might be protected from damage caused by abrasion or compression.

The ratio of broken pollen grains of Pinus to the total number of Pinus grains has been used by Martin (1958b; Martin, Schoenwetter, and Arms, 1961) as an index of pollen preservation, and changes in the ratio used as evidence of changes in the influx of rebedded material (Martin, 1958b, p. 487). Pinus pollen is infrequent in the late-Wisconsin sediments of Andree Bog, and the breakage of Picea pollen, which is similar morphologically, was investigated instead. The percentage of broken Picea pollen was calculated from the ratio $\frac{m}{2n + m}$, where m is the number of half-grains (single bladders) and n is the number of entire grains; this ratio is comparable to the one used by Martin. The results are given as a curve in figure 8. There is clearly no positive correlation between the percentage of broken Picea grains and either the percentage of secondary redeposited pollen or the percentage of deteriorated grains. The higher percentage of broken Picea pollen above 581 cm is instead related to the sediment lithology and is largely if not entirely an artifact of the method of preparation. The Scenedesmus-gyttja above 581 cm is highly compact, elastic, and gel-like, and it resisted all attempts at dissolution by chemical means. Mechanical disaggregation by vigorous stirring was necessary throughout its preparation to maintain dispersal of the fine particles, and such treatment broke many pollen grains, as was demonstrated by comparison of portions of one sample subjected to different preparation techniques. Dispersal of the silty sediment below 581 cm was easily accomplished with little stirring. The percentage of broken

conifer grains at this site is thus related to the preparation technique and has no value whatsoever either as an index of pollen preservation in the untreated sediment or as an indicator of redeposition.

Interpretation of penecontemporaneous redeposited pollen.

The recognition that pollen derived from penecontemporaneous redeposition may make up a significant fraction of the pollen sum in the lower spectra of the Andree Bog diagram (fig. 8) urges caution in interpreting the fluctuations in the pollen curves below the Betula subzone. The sharp peaks of Picea at 600 and 609 cm, of Populus tremuloides-type at 600 cm, of Cyperaceae at 605 cm, of Artemisia and Ambrosia-type at 600 cm, and possibly of Fraxinus nigra-type and Quercus at 609 cm are all more reasonably interpreted as the result of an influx of pollen washed in with plant litter from the surrounding slopes than as the reflection of fluctuations in the atmospheric pollen rain. Some of the Picea pollen is certainly redeposited, for microsporangia containing immature pollen grains are common in the litter horizons.

The three litter horizons analysed (at 600, 605, and 609 cm) are sharply dissimilar in pollen content. The obvious inference is that each layer of litter, together with its content of pollen, was derived from a source area with a different local vegetation. Thus the possibility is opened that spectra heavily contaminated by penecontemporaneous redeposition can be used to reconstruct the local plant communities near the site--a possibility denied by pollen spectra obtained from a large open basin where almost all of the pollen comes from the atmospheric pollen rain. For example, the peaks of Picea, Populus tremuloides-type, Artemisia, and Ambrosia-type at 600 cm suggest derivation from an upland area where spruce forest borders prairie--a situation where these taxa could be found in close contact. The spectrum from the

litter horizon at 609 cm, which in the core is indistinguishable from the layer at 600 cm, suggests on the other hand a more densely forested source area.

The presence of conspicuous fluctuations of a pollen type in spectra that contain penecontemporaneous redeposited pollen is good evidence that the taxon from which the pollen is derived was present in the neighborhood of the site. The prominent peak of Populus tremuloides-type at 600 cm is thus a convincing demonstration that Populus was a constituent of the local vegetation. Of greater interest are the smaller peaks of Fraxinus nigra-type and Quercus at 609 cm, for these are trees whose association with Picea is more surprising. The percentages of both types are too small to permit certainty but are sufficient to force consideration of the hypothesis that these trees were present in the local flora. The evidence is strengthened by the occurrence of the two types, together with Ostrya/Carpinus, in a more prominent peak at a slightly higher level (525 cm).

Age and origin of the Andree Bog basin.

The original interpretation of the stratigraphy at Andree Bog assumed that there was no interruption in deposition in the Andree Bog basin during the transition from Lake Grantsburg to the restricted postglacial lake that occupied the basin, and that the basin was a depression in the underlying drift that was not completely filled by the sediments of Lake Grantsburg (Cushing, 1962). Evidence obtained later, however, suggests that this assumption is incorrect.

The upper part of the pollen diagram from Andree Bog agrees well with a diagram from Horseshoe Lake, a site about 20 miles to the south. The Betula subzone of the Picea-Larix zone is well developed at both sites, and its base as drawn at Andree Bog matches the lower

boundary defined at Horseshoe Lake. The next lower subzone at Horseshoe Lake, the Fraxinus subzone, is not clearly present at Andree Bog, however. Instead, the pollen spectra are confused by the presence of redeposited pollen, and correlation is impossible. It seems reasonable to suppose that the 45 cm of lake sediment rich in silt and plant detritus below the Betula subzone at Andree Bog was deposited more rapidly than the 75 cm of fine-grained, relatively mineral-free copropel below the same subzone at Horseshoe Lake. If so, then either there are unrecognized hiatuses in the stratigraphy at Andree Bog, or organic sedimentation began earlier at Horseshoe Lake than at Andree Bog. The latter possibility is unlikely, for the Horseshoe Lake basin could not have formed until the melting of the Grantsburg sublobe and the formation of the Anoka Sand Plain was well advanced, and by that time Lake Grantsburg had surely drained completely (Cooper, 1935).

Radiocarbon dates from Andree Bog support the relatively young age of the sediments there. The three available dates, all from the Lamont laboratory, are plotted on the pollen diagram, figure 8. The samples are from a core with 4-inch diameter adjacent to the pollen core and correlated with it by sediment stratigraphy. One date is from the bottom of the Scenedesmus-gyttja and has a radiocarbon age of 11,300 years BP (L-727A+B). The other two dates are from adjacent 1-cm horizontal slices of a litter horizon; the samples were washed and sieved and only the $>61\,\mu$ fraction was submitted for radiocarbon assay. The difference between the dates, 10,800 ± 300 (L-727C) and 11,500 ± 300 (L-727D), is unexpected and remains unexplained, but the older of the dates is considered more probably correct. This judgment is based upon the correlation of the Andree Bog diagram with other pollen diagrams in the region (fig. 12, discussed in detail in the section on

Horseshoe Lake). The pollen diagram from Horseshoe Lake is not directly dated, but its correlation with the nearby North Branch site suggests that organic sedimentation there may have begun as early as 12,500 radiocarbon years ago. Thus the radiocarbon dates confirm the assumption of rapid deposition of the silty sediments at the base of the organic sediments in Andree Bog, and they further suggest that the organic deposition may not have begun until long after Lake Grantsburg had drained.

At the edge of the sediments of Lake Grantsburg only a few miles north of Andree Bog there is evidence that the lake was bounded by stagnant ice at its northern limit, for isolated areas of lake sediments now lie topographically higher than surrounding areas free of sediments. Conceivably such stagnant ice, which was remnant from an earlier advance of the Superior lobe from the northeast, could have lain buried beneath the surface covered by Lake Grantsburg and have melted only after the glacial lake had drained. The sequence of litter horizons interbedded with silt is then reasonably interpreted as inwash and slumping of the vegetation-covered surface as the basin subsided. Thus the formation of the Andree Bog basin probably postdates the draining of Lake Grantsburg, and the search for a pollen record older than those found on the Anoka Sand Plain must turn elsewhere.

Redeposited pollen on the Anoka Sand Plain

The outwash sand that makes up the Anoka Sand Plain was derived from the Grantsburg sublobe and thus might be suspected of containing the same secondary microfossils that are present in the sediments of Lake Grantsburg. Examination of samples of the unoxidized sand beneath the sediments of Cedar Bog Lake and Horseshoe Lake, however,

revealed only a very few indeterminable scraps of exine. The sand clearly contains only a minute fraction of the organic matter present in the gray till from which it was derived; undoubtedly the pollen and spores were washed out together with the silt and clay fraction by the meltwater streams that sorted the sand. Sites like Cedar Bog Lake and Horseshoe Lake whose drainage basins are entirely in sand of the Anoka Sand Plain should then contain negligible amounts of secondary pollen. Furthermore, since there is no other known source of allocthonous sediment for the lakes (except through wind transport), secondary redeposition should be recognizable, as it is at Andree Bog, by the presence of pre-Quaternary microfossils.

In fact, a few pre-Quaternary pollen grains, spores, hystrichosphaerids, and dinoflagellates were identified at Horseshoe Lake, but their number is so small (only nine were seen in all the spectra counted) and their occurrence so scattered that it is safe to say that secondary redeposition has had no effect on the primary pollen spectra from the site. No pre-Quaternary microfossils were noted at Cedar Bog Lake. The occurrence of a single grain in only one spectrum is always suspect, but there can be no doubt that the pollen curves that exceed 1 percent at these sites represent primary pollen.

Conclusions

Although at Andree Bog and on the Anoka Sand Plain secondary pollen does not obscure the details of pollen diagrams, the fact that its presence can be recognized and its source demonstrated allows its effect to be measured quantitatively. In doing so, the present study firmly establishes that the occurrence of pollen of deciduous trees in the Picea-Larix zone in east-central Minnesota can not be due to

secondary redeposition. The interpretation of the pollen assemblage of the Picea-Larix zone remains a critical problem, and is discussed at length in the section on the late-Wisconsin pollen flora.

It is also clear that pollen grains can be redeposited (rebedded) from two kinds of sources. Secondary redeposited pollen is derived from the erosion of older strata containing fossil pollen that itself may have been either deposited directly from the atmosphere or redeposited from still older strata. At Andree Bog the secondary pollen is associated with silt, and the spores and pollen (of Cretaceous and possibly interglacial age) have gone through at least two cycles of redeposition. Penecontemporaneous redeposited pollen, on the other hand, is derived from surface materials containing pollen that came from plants also contributing to the atmospheric pollen rain during the time of redeposition. At Andree Bog the penecontemporaneous redeposited pollen is associated with plant litter derived from surface soil, and the pollen has undergone probably only one cycle of redeposition. The distinction between the two kinds is admittedly arbitrary and can be made easily at Andree Bog only because of the great age difference between the two, and because each is associated with a distinctive sediment type. The presence of penecontemporaneous redeposition is also strongly suspected, however, at Cedar Bog Lake (p. 63), where corroded fern spores and pollen grains are associated with a lake sediment containing many plant fragments (the Dryopteris subzone of the Compositae-Quercus zone in fig. 3).

Although it may seriously distort the record of the regional pollen rain that is the usual goal of pollen stratigraphers, penecontemporaneous redeposition may yield valuable information about the composition of local plant communities or may demonstrate the presence in

the local flora of taxa whose pollen might otherwise be considered to derive from long-distance transport.

Pollen preservation is to some extent dependent upon redeposition. At Andree Bog, corrosion, which perhaps results from attack on the exine by aerobic bacteria, is characteristic of penecontemporaneous redeposited pollen. The degraded condition, which may result from physical abrasion or compression, is typical of the secondary pollen in the till--which agrees with an observation by Iversen (1942). Pollen preservation is sufficiently variable, however, and the causes of poor preservation so little understood, that the degree and kind of preservation cannot be used alone as an indication of redeposition.

LATE-WISCONSIN POLLEN STRATIGRAPHY AT HORSESHOE LAKE

The geomorphic development of the Anoka Sand Plain has been understood in its broad outlines since the work of Cooper (1935). The nature of the vegetation that covered the Sand Plain surface at its inception, and the subsequent development of that vegetation, are still largely matters for speculation, however. Clues to the early vegetation history of the Sand Plain were provided by the work of Artist (1939) and Wilson and Potzger (1943) and were greatly increased by Fries, Wright, and Rubin (1961). The present study is an effort to add further to the evidence necessary for a reconstruction of the late-Wisconsin landscape of this part of Minnesota.

The site chosen for a detailed pollen-stratigraphic study of the late-Wisconsin sediments, Horseshoe Lake, is about six miles southwest of the North Branch site investigated by Fries and others (1961) and eight miles northeast of Cedar Bog Lake. Horseshoe Lake lies in the SE$\frac{1}{4}$ sec. 2, T. 34 N., R. 22 W., Isanti County (fig. 1). It is part of a chain of lakes that can be traced southwest across the Anoka Sand Plain nearly to the Mississippi River.

The present vegetation surrounding Horseshoe Lake is typical of this part of the Anoka Sand Plain. Quercus ellipsoidalis is the dominant tree on much of the upland, with Quercus macrocarpa locally important in open stands. Populus grandidentata, Populus tremuloides, Quercus alba, and Betula papyrifera are of lesser importance in the canopy. Pinus strobus is common in the forest and clearings bordering the lake. Understory species include Corylus americana, Prunus virginiana, Prunus pensylvanica, Amelanchier sp., Acer rubrum, Celastrus

scandens, Vitis riparia, and Parthenocissus inserta. The lake is bordered by steeply sloping banks, and only a narrow zone of emergent aquatics surrounds the open water, except in the shallower west arm of the lake.

Sediment stratigraphy

The morphometry of the Horseshoe Lake basin and the distribution of the sediments within it have been thoroughly investigated by Thomas (1959). The boring made for the present study was located at the point of deepest sediments in the east basin of the lake, as shown in Thomas' profiles. In the following description of the core, the depths given are measured from the water level at the time of sampling (March 1960).

0 - 105 cm: Open water.

105 - 625 cm: Coarse-detritus copropel. Ld^0 3, Dh 1, Dg +; dark brown, very soft to firm, elas 2, calc 0 above 575 cm, increasing gradually to calc 2 below. Lower contact gradational over 1 cm.

625 - 909 cm: Fine-detritus marly copropel. Ld^0 3, Dh 1, Lc +; medium olive-brown, firm, elas 3, calc 3. Finely interbedded with Ld^0 3, Dg 1; dark olive, calc 0 to 2. Lower contact gradational over 1 cm.

909 - 921 cm: Fine-detritus copropel. Ld^1 3, Dg 1, Dh +; dark gray, very firm, elas 3, calc 0. Najas seeds abundant. Microscopic estimate (after HF treatment): pyrite rare, cellular fragments abundant, hyphae very rare, pollen infrequent, algae common (Pediastrum, Tetraedron, Botryococcus), chitin infrequent, charcoal infrequent. Lower contact gradational over 2 cm.

921 - 1042 cm: Copropel. Ld^0 4; dark gray, very firm, elas 4, calc 0. Microscopic estimate (after HF treatment): pyrite rare (increases to common below 1000 cm), cellular fragments

abundant, hyphae very rare, pollen common, algae common (Scenedesmus, Coelastrum, Pediastrum, Botryococcus, Tetraedron, others), chitin common, charcoal rare. Gradual increase in Ga below 1005 cm; lower contact very gradational.

1042 - 1089 cm: Sandy copropel. Ld^0 2, Ga 2; medium olive-gray, very firm, elas 4, calc 0. Microscopic estimate (after HF treatment): pyrite common, cellular fragments common, hyphae very rare, pollen common, algae common (Coelastrum, Scenedesmus, Tetraedron, Pediastrum, Botryococcus, others), chitin common, charcoal rare. Lower contact sharp.

1089 - 1091 cm: Coarse-detritus copropel. Ld^2 2, Dl 1, Dg 1, Ga +; dark brown, very firm, elas 4, calc 0. Microscopic estimate (after HF treatment): pyrite rare, cellular fragments abundant, hyphae common, pollen rare, algae not seen, chitin very rare. Lower contact sharp.

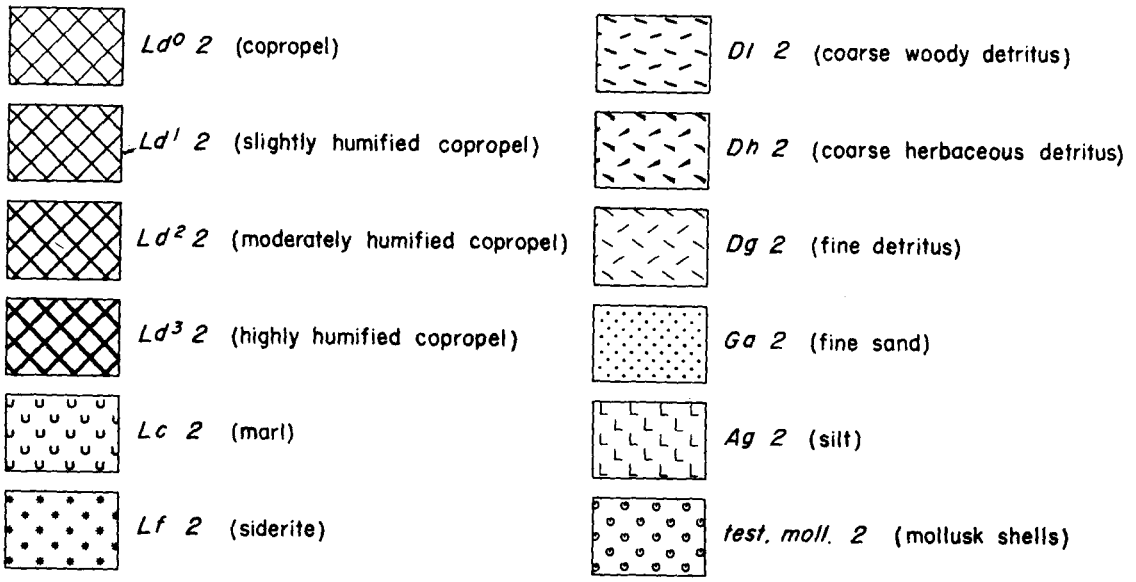
1091 - 1250+ cm: Fine sand. Ga 4; medium gray, firm, elas 0, calc 1. Microscopic estimate (after HF treatment): cellular fragments rare.

Pollen zones

The pollen diagram from Horseshoe Lake (figure 10) shows only the lower part of the boring. The pollen zones into which it is divided are the same as those defined at Cedar Bog Lake. The highest spectrum in the diagram is placed in the Ulmus subzone of the Compositae-Quercus assemblage zone. The Pinus-Pteridium assemblage zone is essentially the same as at Cedar Bog Lake. The Picea-Larix assemblage zone, however, is better developed at Horseshoe Lake than at Cedar Bog Lake. It is divided into the following two subzones.

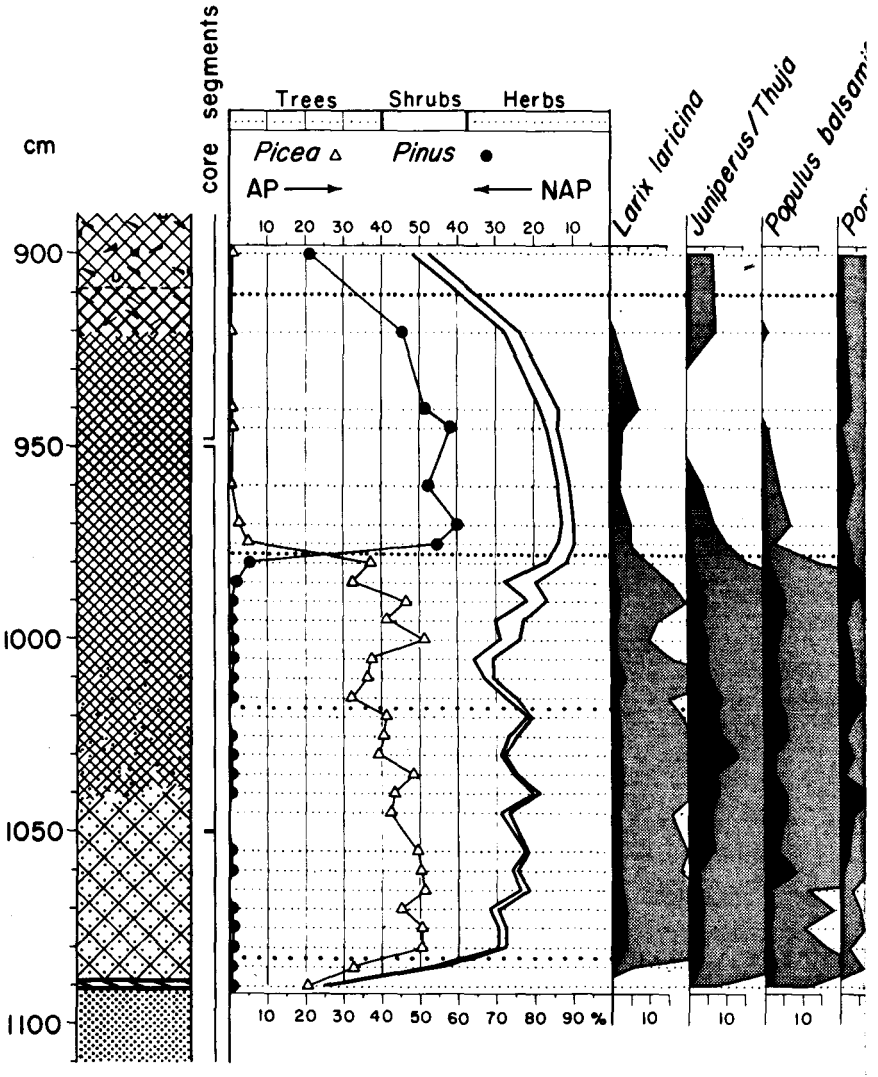
Fraxinus subzone. Fraxinus dominates the pollen of deciduous trees in the lower subzone, and Populus and Juniperus/Thuja reach high

F i g u r e 1 0 . Pollen diagram of Horseshoe Lake. Scale at base of diagram gives percentages for black silhouettes; stippled silhouettes are exaggerated 10X scale. Abbreviations: AP = arboreal pollen, NAP = non-arboreal pollen, undiff. = undifferentiated, Indet. = indeterminable, Sphag. = Sphagnum, pre-Q = pre-Quaternary microfossils. Symbols used in the sediment lithology column are given below.

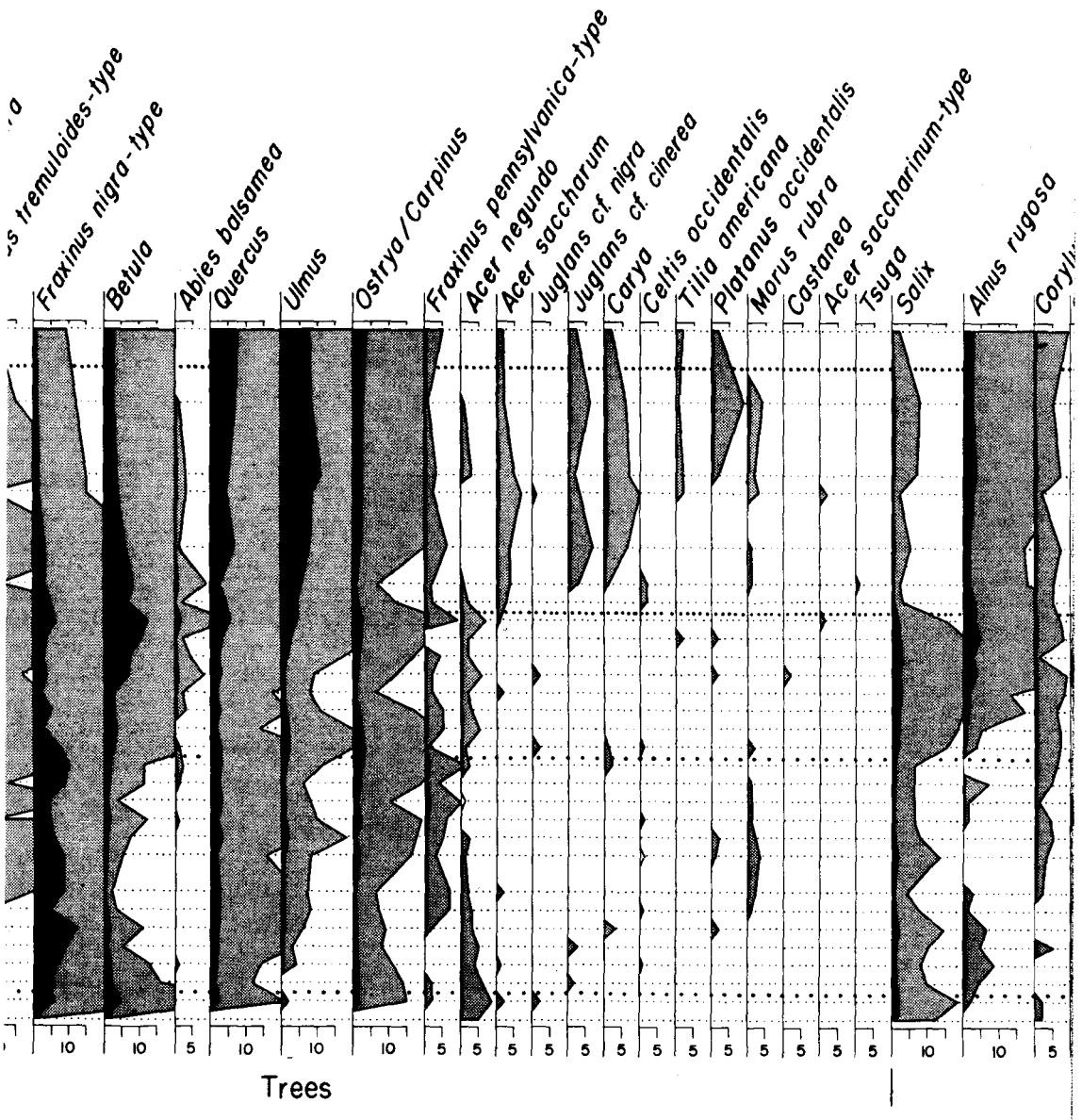


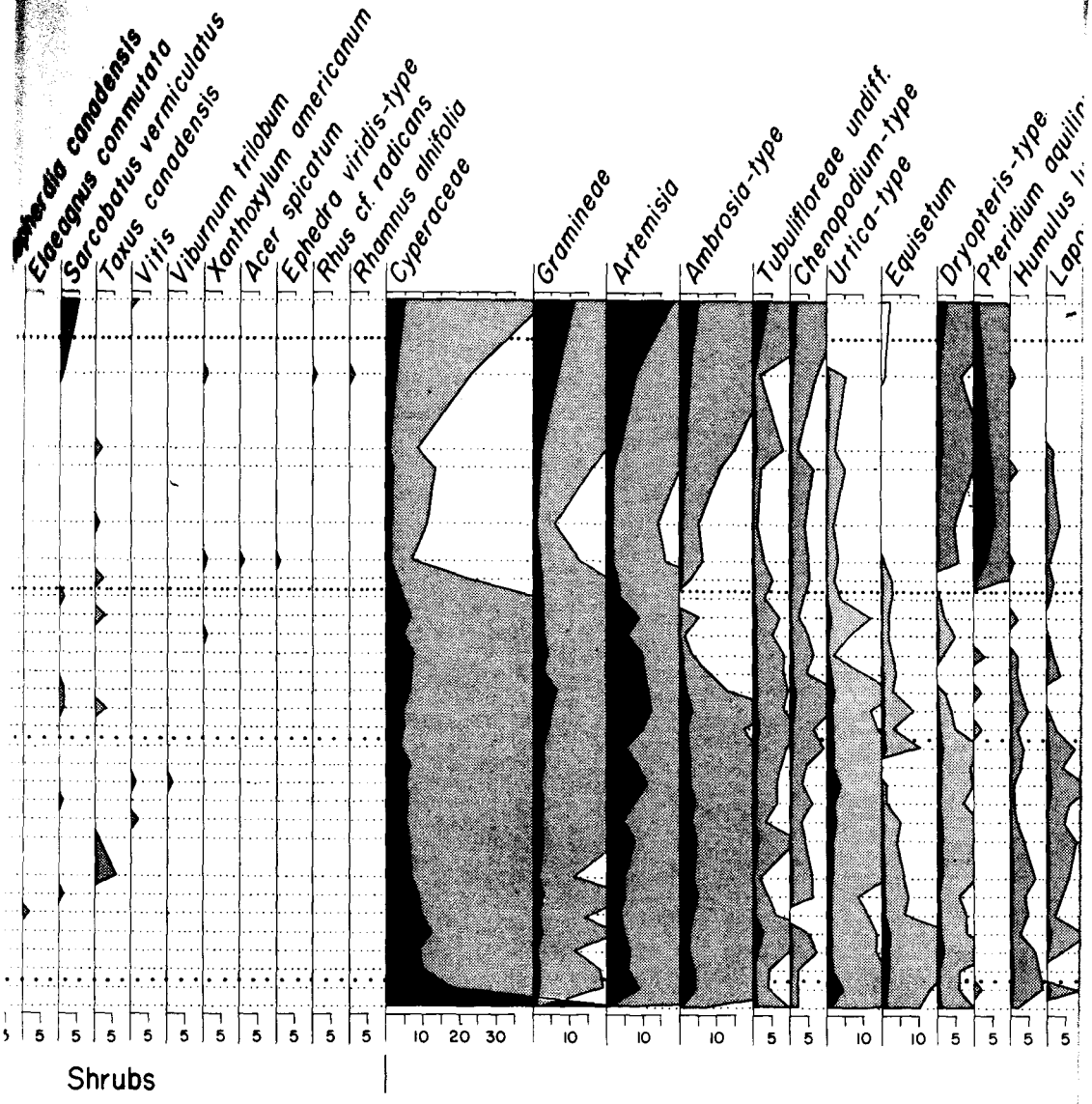
Density of symbols indicates proportion of component in the sediment. Density shown here indicates a proportion of 50%.

HORSESHOE LAKE Isa

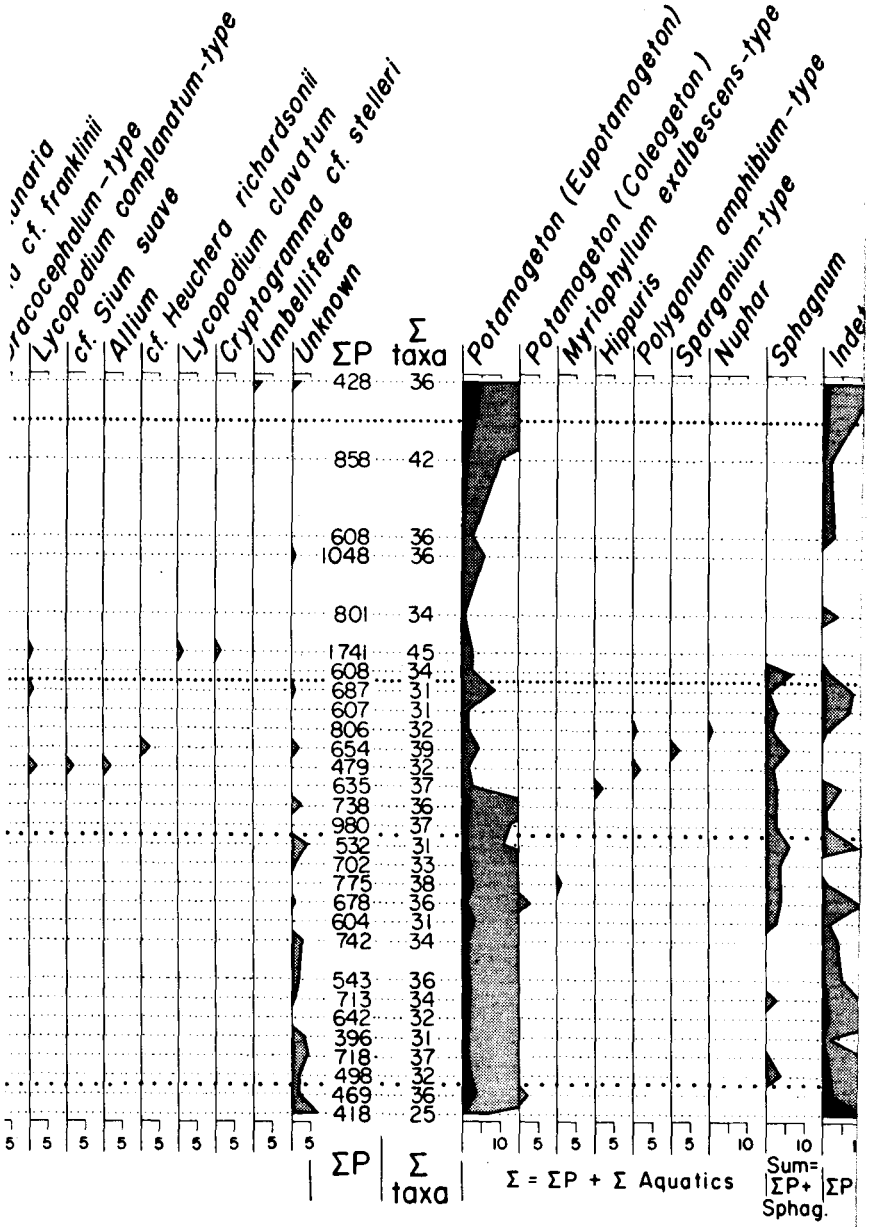


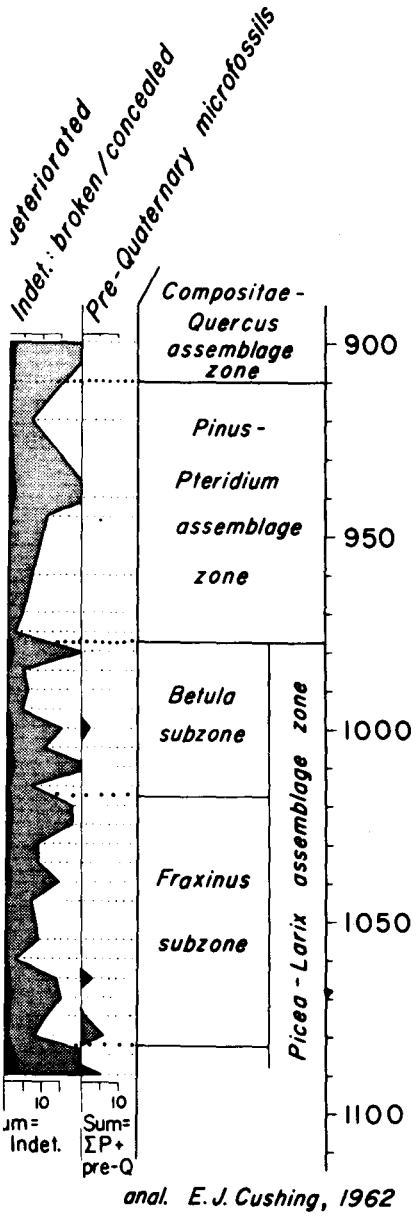
ıti Co., Minnesota




Elaeagnus commutata
Sarcobatus vermiculatus
Taxus canadensis
Vitis
Viburnum trilobum
Xanthoxylum americanum
Acer spicatum
Ephedra viridis-type
Rhus cf. radicans
Rhamnus alnifolia
Cyperaceae
Gramineae
Artemisia
Ambrosia-type
Tubuliflorae undiff.
Chenopodium-type
Urtica-type
Equisetum
Dryopteris-type
Pteridium aquilin
Humulus l
5 5 5 5 5 5 5 5 5 5 5 5
10 20 30
10
10
10
5 5
10
10
5 5 5 5
Shrubs

-type
Thalictrum cf. dasycarpum
Thalictrum confine-type
Thalictrum cf. dioicum
Typha latifolia
Tofieldia glutinosa
Athyrium felix-femina
Cruciferae
Adiantum
Plantago major
Hedysarum
Rumex cf. mexicanus
Rosaceae
Euphorbia (Chamaesyce)
Selaginella selaginoides
cf. Mertensia paniculata
Iva xanthifolia-type
Ericaceae
Phlox pilosa-type
Iva ciliata-type
cf. Gymnocarpium
cf. Penthorum sedoides
Ranunculus-type
Petalostemum candidum-type
Xanthium
Hydrophyllum cf. virginianum
Galium
Plantago rugelii
Botrychium
5
Herbs


unaria
cf. franklinii
racocephalum-type
Lycopodium complanatum-type
cf. Sium suave
Allium
cf. Heuchera richardsonii
Lycopodium clavatum
Cryptogramma cf. stelleri
Umbelliferae
Unknown
ΣP
Σ taxa
Potamogeton (Eupotamogeton)
Potamogeton (Coleogeton)
Myriophyllum exalbescens-type
Hippuris
Polygonum amphibium-type
Sparganium-type
Nuphar
Sphagnum
Inde
428 36
858 42
608 36
1048 36
801 34
1741 45
608 34
687 31
607 31
806 32
654 39
479 32
635 37
738 36
980 37
532 31
702 33
775 38
678 36
604 31
742 34
543 36
713 34
642 32
396 31
718 37
498 32
469 36
418 25
5 5 5 5 5 5 5 5 5
10 5 5 5 5 5 10 10
ΣP
Σ taxa
Σ = ΣP + Σ Aquatics
Sum= ΣP+ Sphag.
ΣP



anal. E. J. Cushing, 1962

values. Betula pollen is relatively infrequent, as is Ulmus and Salix. Artemisia and Cyperaceae dominate the non-arboreal pollen, and Ambrosia-type, Urtica-type, and Laportea-type are relatively important. The top of the subzone is placed at a sharp decrease in Fraxinus just before the rise of Betula; the base, at Horseshoe Lake, is marked by a rise in Fraxinus pollen just above a sharp decline in non-arboreal pollen.

Betula subzone. Betula pollen is present in moderate percentages at the beginning of this subzone and rises within it to dominate the deciduous tree pollen. Pollen of shrubs is relatively important; Salix, Alnus, and Corylus all have significant increases in the subzone. Artemisia dominates the non-arboreal pollen. Other relatively important contributors to the pollen sum in the subzone are Gramineae, Abies, Ostrya/Carpinus, and Ulmus. Fraxinus, Populus, and Quercus remain important throughout. The top of the subzone is the top of the Picea-Larix zone, placed where the relative frequency of Picea pollen decreases sharply. The subzone base is placed at a small but sharp increase of Betula pollen accompanied by a more gradual rise in Salix.

Comparison and correlation with other diagrams

The pollen diagram from Horseshoe Lake compares well with other diagrams from the region. Its agreement with the diagram from Cedar Bog Lake is close even in the details of many of the curves in the Betula subzone of the Picea-Larix zone. The equivalent of the bottom of the Cedar Bog Lake diagram can thus be located with fair precision at 10.2 meters in the Horseshoe Lake core. The close correspondence of diagrams from two sites only eight miles apart suggests that the equivalent changes to be recognized in them are the result of changes in regional vegetation and are thus time-correlative.

Interestingly, the rate of sedimentation during the Betula subzone appears to have been four or five times more rapid at Cedar Bog Lake than at Horseshoe Lake.

This difference in sedimentation rate is partly responsible for the apparent abruptness of the change from Picea to Pinus dominance in the Horseshoe Lake diagram when compared to the sequence at Cedar Bog Lake. Nevertheless, the difference in the zone transition at the two sites seems to be real, and it is accentuated by a comparison of the Betula curve. At Horseshoe Lake Betula pollen reaches its maximum within the Picea-Larix zone and then declines, but at Cedar Bog Lake the curve continues to increase to a higher percentage in the Pinus-Pteridium zone.

The Fraxinus subzone of the Picea-Larix zone, so well developed at Horseshoe Lake, is represented at Cedar Bog Lake, if at all, only by the lowest two spectra.

Comparison with the pollen diagram from a buried peat near North Branch (Fries and others, 1961) is difficult because the North Branch stratigraphy is clearly incomplete. The lowest and thickest peat layer there, however, yielded an apparently continuous though short pollen record. The lower analyses from the site (100 to 160 cm at profile B, figure 6, Fries and others, 1961) are shown in figure 11, where they are recalculated on a sum of total pollen for easier comparison with the Horseshoe Lake diagram. The relatively high percentages of Cyperaceae, Ambrosia (Tubuliflorae), and Fraxinus pollen in the lower spectra from North Branch suggest correlation with the lower part of the Fraxinus subzone. Particularly remarkable is the similarity between the peaks of Artemisia and Betula at 151 cm at North Branch and the peaks of the same types at 1085 cm at Horseshoe Lake, although

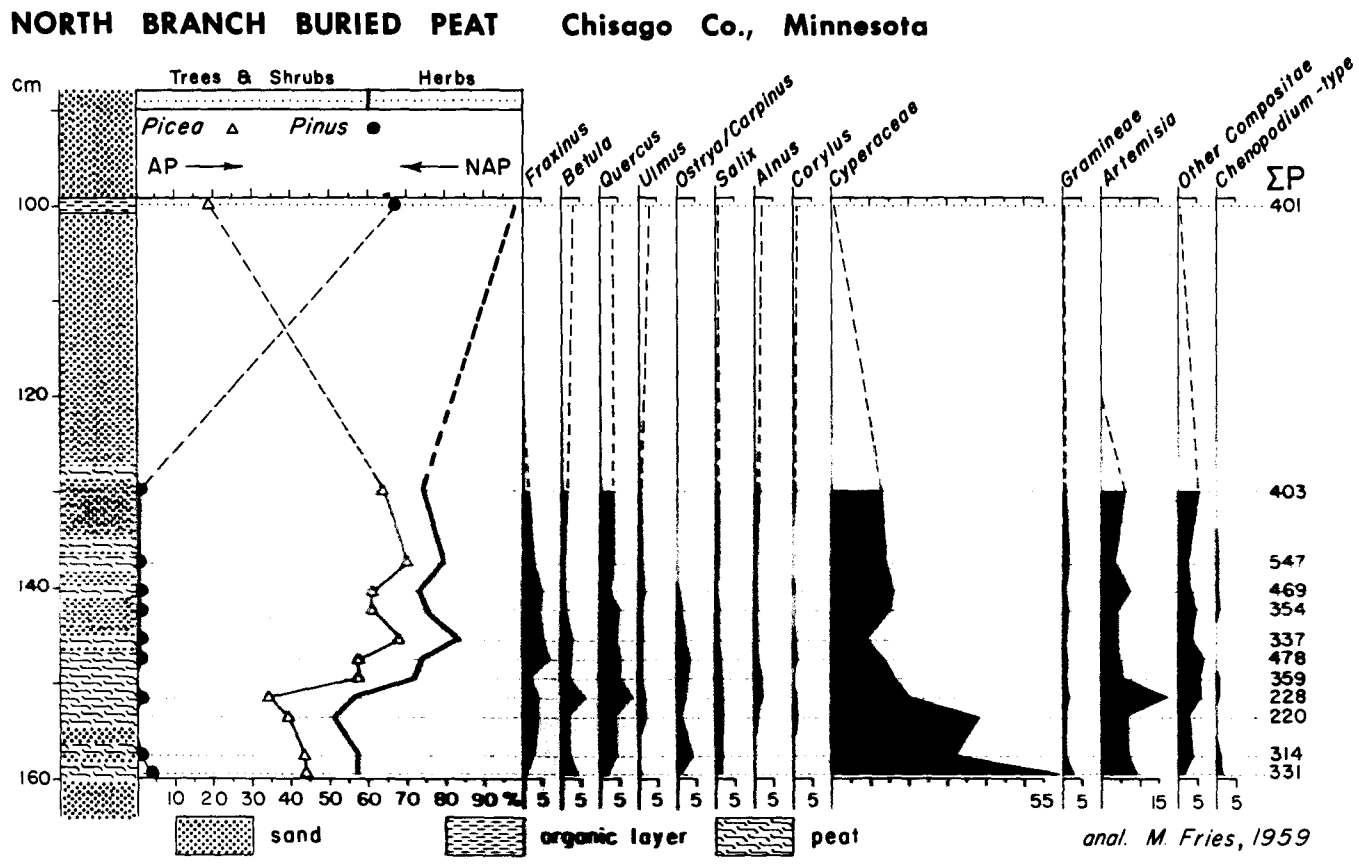


Figure 11. Pollen diagram of North Branch buried peat. Redrawn from Fries, Wright, and Rubin (1961) on calculation sum of total pollen.

it is risky to base a correlation on the equivalence of single spectra.

At Andree Bog (Fig. 8) the Betula subzone of the Picea-Larix zone seems as pronounced as at Horseshoe Lake. The spectra below it are confused by the influx of redeposited pollen and are not zoned. The Fraxinus subzone is represented, but Fraxinus pollen does not seem to be so important as at Horseshoe Lake.

Comparison with the diagrams from Dakota County, 45 miles to the south (Patten, 1959; Winter, 1961, 1962) is not so certain. Betula pollen is common throughout the A zone of Winter (1962), and both his A-a and A-b zones are here included in the Betula subzone of the Picea-Larix zone. When detailed diagrams have been prepared from sites between Horseshoe Lake and Kirchner Marsh it may appear that the Fraxinus subzone as defined at Horseshoe Lake changes to the south by an increase in Betula pollen until it corresponds to the A-a zone as defined at Kirchner Marsh. It is unfortunate that Populus and Juniperus/Thuja, two pollen types that are important components of the pollen sum in the Picea-Larix zone at Horseshoe Lake, were not included in the Kirchner Marsh counts.

The Pinus-Pteridium zone (zone B of Winter, 1962) at Kirchner Marsh corresponds very well to the same zone at Horseshoe Lake and Cedar Bog Lake, if one assumes that the category of "trilete spores" in the Kirchner Marsh diagram (Winter, 1961) is chiefly made up of Pteridium aquilinum spores. The transition from the Picea-Larix to the Pinus-Pteridium zones is somewhat different in the southern diagrams, however. There is an appreciable interval between the decline of Picea pollen and the abrupt increase of Pinus that is occupied by the Betula maximum, accompanied by pronounced maxima of Alnus and Abies.

The difference is more striking in the Lake Carlson diagram (Patten, 1959), where Pinus does not reach percentages so high as at Kirchner Marsh.

A pollen diagram from Madelia, Minnesota, 120 miles southwest of Horseshoe Lake (Jelgersma, 1962), differs from figure 10 even more than do the Dakota County diagrams. A pollen zone at the base of the Madelia diagram (Jelgersma's zone I) is not clearly represented at Horseshoe Lake. The zone at Madelia is characterized by high percentages of Cyperaceae and Salix pollen, relatively low Picea and Fraxinus, and appreciable amounts of Quercus, Elaeagnus commutata, Shepherdia canadensis, and Compositae (probably Ambrosia-type) pollen; it is here informally referred to as the Cyperaceae-Salix assemblage zone. The spectra with high values of non-arboreal pollen at the base of the diagrams from Horseshoe Lake, North Branch, Andree Bog, and Kirchner Marsh might be referred to this zone, but they do not show the high values of Salix pollen that characterize the zone at Madelia. It will be argued later that pollen spectra from the basal sediments of a site should be interpreted and traced with caution, and no attempt is therefore made to find equivalents of Jelgersma's zone I at the other sites.

The next higher zones at Madelia (zones II and III of Jelgersma), however, clearly belong to the Picea-Larix zone as it is here defined. The lower part (from approximately 260 cm to 278 cm in Jelgersma, 1961, fig. 2) corresponds to the Fraxinus subzone, and the upper part (the remainder of Jelgersma's zone II plus zone III) fits the Betula subzone; the major difference is the greater prominence of Alnus in the Betula subzone of the southern diagram.

The Pinus-Pteridium zone, however, is missing at Madelia, for Pinus pollen never exceeds five percent in the diagram. In place of that zone is a new one that Jelgersma designates zone IV. A maximum of Betula pollen characterizes the zone, together with relatively high Abies and Ulmus; non-arboreal pollen is low in amount, except for Filicales (unfortunately not further identified). Evidently this zone is similar to the interval between the Picea-Larix and Pinus-Pteridium zones noted at Kirchner Marsh, and it is here informally designated the Betula-Abies assemblage zone. The uppermost spectra of the Madelia diagram, Jelgersma's zone V, may properly be placed in the Ulmus subzone of the Compositae-Quercus zone.

The zone equivalences suggested here are indicated in figure 12, which is a correlation chart of the late-Wisconsin and early post-Wisconsin zones in southern Minnesota as dated by the radiocarbon method. The available radiocarbon dates from Madelia, Kirchner Marsh, Cedar Bog Lake, North Branch, and Andree Bog are plotted with the standard deviations indicated. No dates are available for Horseshoe Lake, and the zone boundaries at that site are assumed to be the same age as the equivalent boundaries at Cedar Bog Lake, the nearest site. The dates from Andree Bog are used to place the lower zone boundaries there; the upper boundaries at that site are uncontrolled and are assumed to be the same age as at Cedar Bog Lake. The two dates from North Branch are not precisely located with respect to the pollen diagram, but the older is assumed to date the base of the profile. The base of the Horseshoe Lake diagram is dated on the basis of its tentative correlation with the North Branch diagram. Where they are not directly dated, zone boundaries are placed in the chart by linear interpolation or extrapolation from the nearest pair of dates at the site.

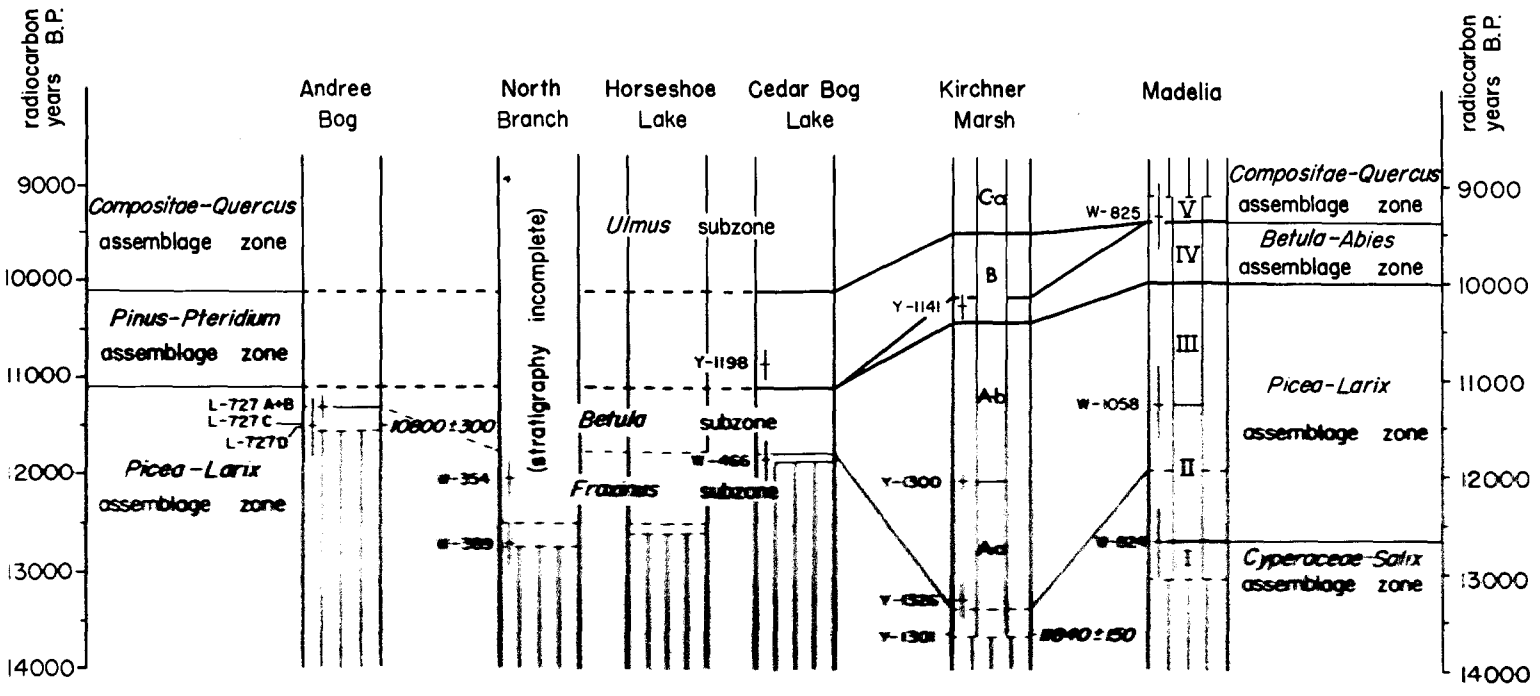


Figure 12. Correlation of late-Wisconsin and early post-Wisconsin pollen zones in southern Minnesota. Radiocarbon dates are shown by crosses: the vertical line indicates the reported standard error. Anomalous dates (L-727C, Y-1301) are given in italics at their proper stratigraphic position. Pollen zones according to Winter (1962) at Kirchner Marsh and Jelgersma (1962) at Madelia are given in the central column for those sites.

Although the number of both radiocarbon dates and pollen diagrams is fewer than desirable for good control, the correlation chart suggests that the top of the Picea-Larix zone is not isochronous from central to southern Minnesota. The significance of this observation will be discussed later.

The detailed diagrams from Weber Lake (Fries, 1962), in the northern conifer-hardwood forest of northeastern Minnesota, show few similarities to the group of diagrams in southern Minnesota just discussed. Although the same pollen types are present in all the diagrams, the distribution of these is quite different at Weber Lake, and the pollen zones present in the south cannot be found there. It appears that the differences between the vegetation of northeastern and southeastern Minnesota were at least as pronounced in the past as they are at present. Pollen diagrams from intermediate sites must be available before the relationship of the southern pollen zones to the northern zones will become clear.

Two diagrams from central and eastern Wisconsin by West (1961) are from latitudes comparable to those of the southern Minnesota sites. The Minnesota and Wisconsin diagrams are remarkably similar. The Picea-Larix zone is well marked in the Wisconsin diagrams; it comprises West's zones 1 through 4. The subzones are more difficult to compare, and no direct equivalents of the southern Minnesota subzones are suggested here, although the same general components and trends can be observed in West's diagrams. West's zone 5 is clearly comparable to the Pinus-Pteridium zone.

A late-Wisconsin diagram from southern Michigan (Andersen, 1954) is also similar to the southern Minnesota diagrams. The chief differences are the absence of Larix and the relative abundance of

Quercus and Ostrya/Carpinus pollen in the lower part of Picea-dominated zone in Michigan. Betula pollen is relatively scarce in Andersen's diagram, and Fagus there joins the other deciduous-tree pollen types that are found at Horseshoe Lake.

LATE-WISCONSIN LANDSCAPE IN EAST-CENTRAL MINNESOTA

Topography and physiographic processes

Before a reconstruction of the late-Wisconsin vegetation is attempted, it is useful to consider the characteristics of the land surface available for plant occupation. The hypothesis is advanced here that changes in topography that were peculiar to the late Wisconsin had an important effect upon the vegetation and its record in pollen diagrams.

The basal organic sediment at Horseshoe Lake and Cedar Bog Lake is a peculiar thin layer of detritus copropel. It is rich in wood and fungal remains and yields on washing a variety of macrofossils, including seeds, mosses, fungal mycelia and rhizomorphs, wood and bark fragments, and conifer needles (Picea and Larix). The layer typically rests with sharp contact on sand, which may contain a few woody tissue fragments in the upper few centimeters but is essentially barren of pollen a few millimeters below the contact. At Cedar Bog Lake the sand is noncalcareous to a depth of 22 cm below the contact but is weakly calcareous at greater depth (in a deeper core adjacent to the pollen core). At Horseshoe Lake the sand is weakly calcareous immediately below the contact, although the basal organic sediment is not calcareous. Similar layers of plant detritus are present at Andree Bog (p. 94) and commonly occur as the basal organic deposit in Minnesota lakes developed on either sorted drift or till.

These layers are believed to be similar in character and origin to the Allerød-mull described in Denmark by Hartz (1912). Such a layer represents the surface accumulation of plant litter on the

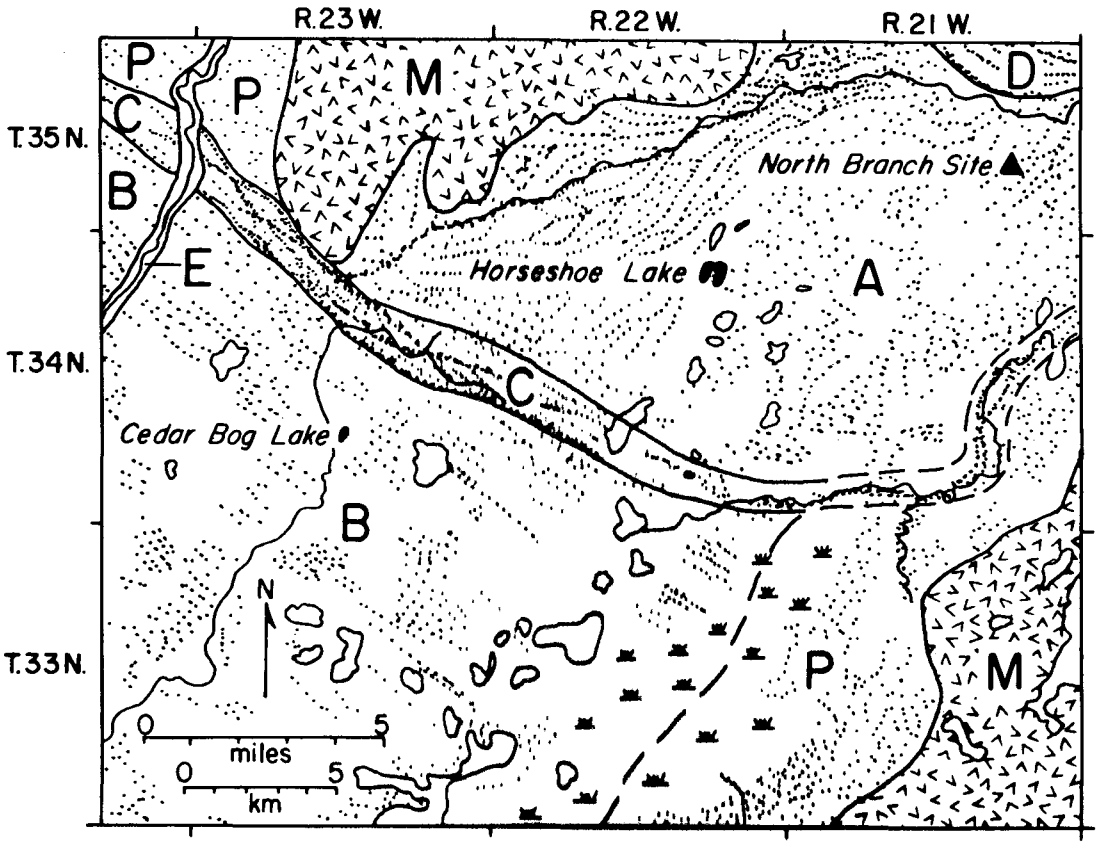
ground above a buried ice mass before that ice block melted to form a lake basin. The leaching of the sand beneath the layer (at Cedar Bog Lake) suggests incipient soil formation and reinforces the view that the layers are equivalent to the A_0 and A_{00} horizons of pedology. The plant detritus may be essentially in place and undisturbed, or there may have been some reworking or slumping of the surface as the basin floor subsided. The name "Allerød-mull" bears time implications and could not be applied to these layers without confusion; the term litter horizon is proposed here as a substitute.

The pollen content of a litter horizon often differs sharply from that of the lake sediments immediately above it. This is to be expected, since the litter itself, and presumably much of the pollen contained within it, is derived from a local plant community that may or may not be representative of the total vegetation of the area. The clearest example is provided at Horseshoe Lake. The lowest pollen spectrum in the diagram of that site (fig. 10) is from the litter horizon. The spectrum includes high values of Cyperaceae and Tofieldia glutinosa, types that decline sharply in abundance in the sediment just above. The combination of these pollen types with the litter suggests the remnants of a sedge meadow that existed on the site of Horseshoe Lake before the buried ice mass beneath melted away. The pollen spectrum from the litter horizon at Cedar Bog Lake (fig. 3), on the other hand, includes a high relative frequency of Picea pollen and comparatively little non-arboreal pollen. Evidently a spruce forest existed on the site before subsidence of the basin. This conclusion is supported by the abundance of wood and Picea needles in the horizon; the layer is similar to the litter to be expected beneath a modern spruce forest.

Correlation of the Horseshoe Lake and Cedar Bog Lake diagrams (fig. 12) indicates that the age of the litter horizons, and thus the date of formation of the lake basins, is not everywhere the same. If the correlation between Horseshoe Lake and North Branch is valid and the radiocarbon dates from the sites are correct, the age difference may have been as great as 900 radiocarbon years. It is not clear whether the North Branch site is an ice-block pit or an initial depression in the outwash-plain surface; if the latter, the buried peat there may be among the earliest organic deposits on this part of the Anoka Sand Plain. The pollen diagrams and radiocarbon dates do indicate a succession in the opening of basins to deposition from the northeast (North Branch) to the southwest (Cedar Bog Lake).

These age differences appear to be closely related to the geomorphic history. The geomorphic map (fig. 13) and stage diagrams (figs. 14 and 15) illustrate a working hypothesis of the development of the Anoka Sand Plain in the area surrounding the three sites. The hypothesis is based on reconnaissance observations in the field and on maps and aerial photographs, and the figures are largely diagrammatic. Many details preserved in the present topography and deposits remain to be studied.

The land surface over which the Grantsburg sublobe advanced was marked by a series of subparallel drainageways trending northeast-southwest. These drainage channels are the dominant geomorphic feature over a large portion of east-central Minnesota (Wright, 1956) and apparently were formed by subglacial drainage from the wasting Superior lobe. Many of the channels contain esker segments; the channel that now contains Horseshoe Lake is one of these, for a ridge flanked by depressions can be traced for several miles northeast and southwest of



GEOMORPHIC UNITS

E Rum River valley

D St. Croix River terrace

P undifferentiated outwash

C Isanti outwash channel

B Bethel outwash plain

M undifferentiated moraine

A Oxford outwash plain

Figure 13. Geomorphology of the Cedar Bog Lake - Horseshoe Lake area.

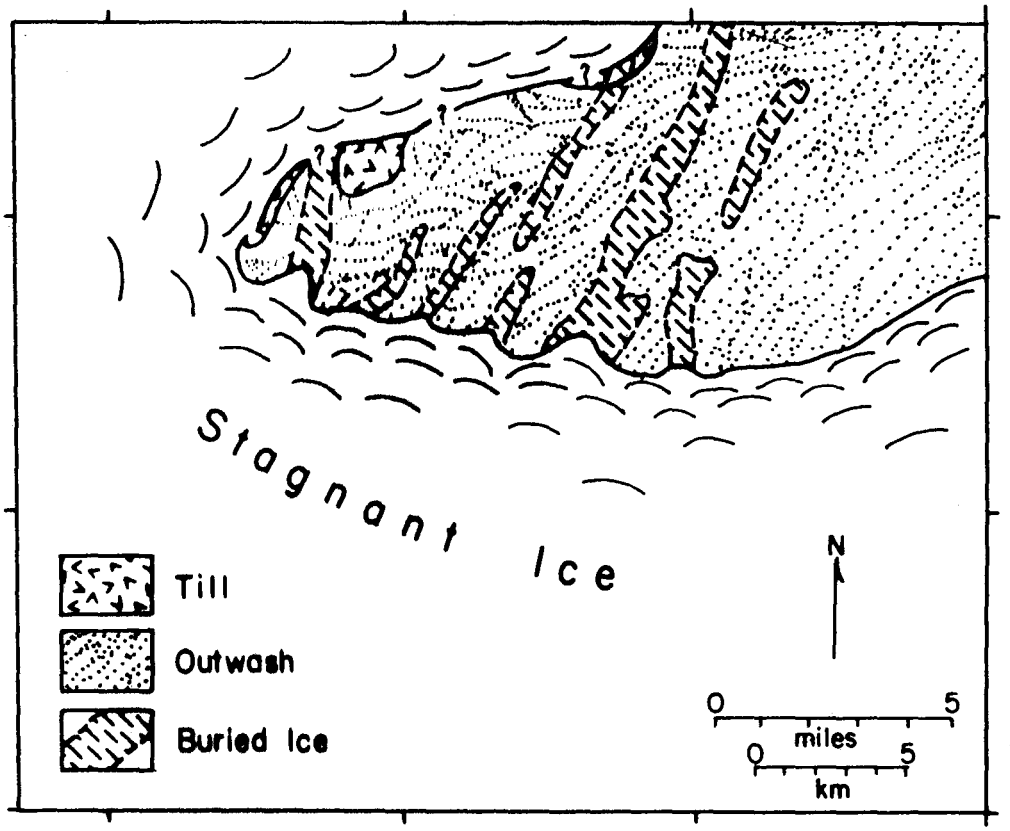


Figure 14. Formation of the Oxford outwash plain. Map area same as figure 13.

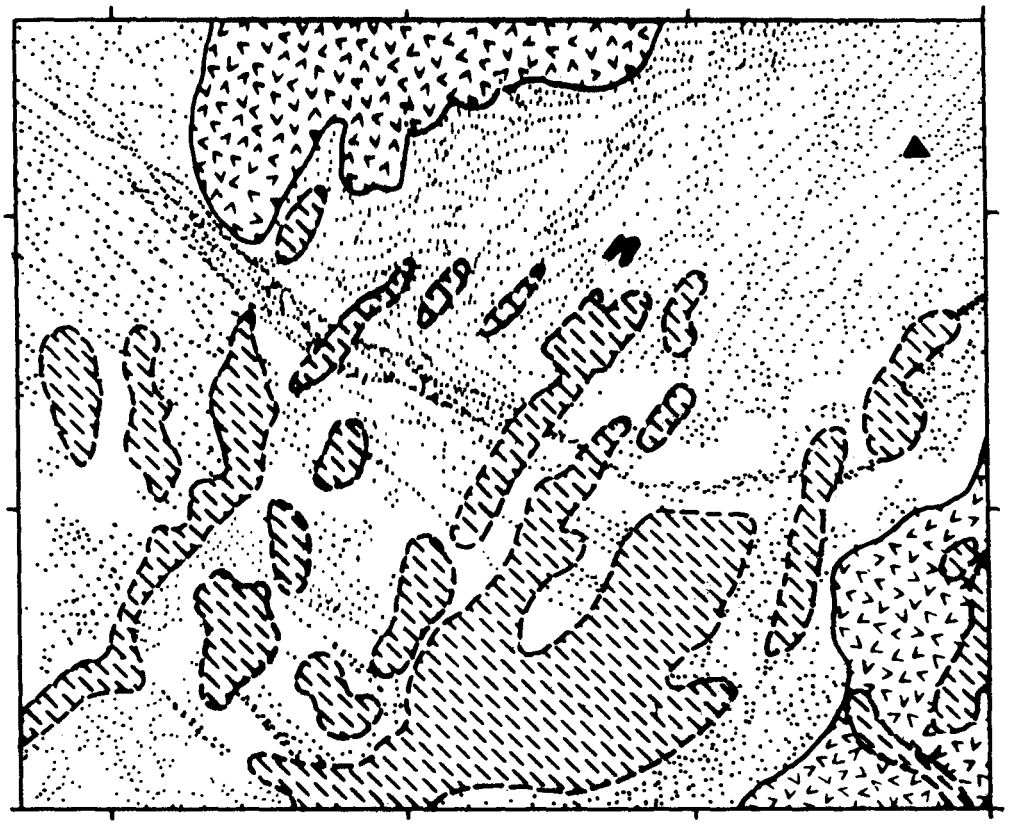


Figure 15. Formation of the Bethel outwash plain. Map area same as figure 13.

the lake--it is in fact this esker ridge that crosses Horseshoe Lake to give that lake its distinctive shape.

It is not clear whether the drainage channels of the Superior lobe in the Horseshoe Lake area were completely free of Superior-lobe ice at the time of advance of the Grantsburg sublobe. There is evidence that considerable stagnant ice still existed north of the edge of the Grantsburg sublobe at its maximum extent, and it has been argued (Cushing, in manuscript) that the extensive mixing and interlayering of drifts in the Minneapolis area was the result of overriding of stagnant Superior-lobe ice by the Grantsburg sublobe. Whatever its original source, it is clear that ice remained in the old drainage channels in the Horseshoe Lake area after most of the Grantsburg sublobe had wasted, and it was the melting of these partly or completely buried ice masses that produced the basins marking the sites of the channels in the present landscape.

The broad outlines of the wastage of the Grantsburg sublobe and the formation of the Anoka Sand Plain were recognized by Cooper (1935), and the present interpretation differs only in details. Cooper's concept of the wastage of the sublobe by stagnation and disintegration rather than by orderly retreat of the ice margin provides the most reasonable explanation for the features of the present topography. As the ice downwasted, meltwater streams flowed over the ice surface; evidence of them remains, for example, in the kame about 7 miles north of Horseshoe Lake described by Farnham (1956). Much of the sorting that resulted in the remarkably uniform texture of the outwash of the Anoka Sand Plain may have been done by meltwater streams before they left the surface of the ice.

The first easily discernible stage in the melting of the ice in the Horseshoe Lake area was the formation of an outwash plain in a re-entrant of the ice. This plain is here called the Oxford outwash plain because it occupies most of Oxford township in Isanti County (fig. 13). It is bounded on the north by a till plain, on the west and south by the Isanti outwash channel described below, and on the east and south by the South Branch of Sunrise River. To the east and north it is interrupted by the terraces of the St. Croix River.

The Oxford outwash plain was formed by meltwater streams flowing essentially to the northeast. The braided channel pattern made by the anastomosing streams as they flowed over ice-free terrain can be recognized on aerial photographs of the area and is diagrammatically shown by the dot pattern of figure 14. The ice margin shown in figure 14 is conjectural; probably meltwater streams originated far to the southwest of the margin position shown and flowed over a thin stagnant ice mass. As the ice thinned to the northwest it was dissected into isolated masses, many of which were localized by depressions in the sub-glacial topography. These masses were buried by outwash deposited by the meltwater streams, and their position is marked today by the kettles and elongated depressions that interrupt the outwash plain pattern.

At the time of deposition of the Oxford outwash plain, meltwater from the northern edge of the Grantsburg sublobe probably drained around the north end of the moraine area that extends south from Pine City to Isanti (fig. 1). That area may itself have been largely covered by ice to form a divide in the meltwater drainage of the sublobe, or it may have been free of ice but avoided by meltwater streams because of its slightly higher elevation.

By the time most of the area to the southwest of the Oxford outwash plain was free of ice, the regional drainage off the ice was to the southeast, toward the lowland occupied by the Oxford outwash plain. A second outwash plain then cut across and obscured the headward part of the Oxford outwash plain. This new feature covers a large part of Bethel township in Anoka County and is here named the Bethel outwash plain. Its present extent outside the area of figure 13 is uncertain. It is marked by braided channel patterns that trend northwest to southeast. Like the Oxford plain, the Bethel outwash plain was formed over numerous masses of buried ice that later melted to leave lakes and depressions in the surface. The meltwater apparently collected in the lowland west of Forest Lake and Wyoming and drained northeast along the present course of the South Branch of Sunrise River (fig. 1).

During the deposition of the Bethel outwash plain, the Oxford outwash plain was free of major meltwater streams, and organic sedimentation could begin in depressions like those at the North Branch site and Horseshoe Lake (fig. 15). The time that elapsed between deposition of the Oxford outwash plain and the initial organic deposition at these sites is unknown, however.

At the conclusion of deposition of the Bethel outwash plain the meltwater became concentrated in a prominent channel, here called the Isanti outwash channel because it passes through the town of Isanti (fig. 13). The channel, which is in fact a series of braided stream courses rather than a single well-defined valley, can be easily traced from a point southwest of Spencer Brook in western Isanti County to Stacy in western Chisago County. From Stacy it apparently followed the present course of the Sunrise River to the northeast.

Its source to the west in Sherburne County is less certain. The formation of the Isanti outwash channel may have resulted from the breaching of the postulated ice divide that lay in west-central Isanti County (perhaps trending northeast-southwest in the vicinity of Bradford). The channel may thus have carried the first meltwater from the northern edge of the Grantsburg sublobe around the south end of the morainic area mentioned above. It probably continued to carry water until the Mississippi River valley train (Cooper, 1935, p. 59) became established.

That the Isanti outwash channel flowed over buried ice masses is shown by the presence of depressions that intersect it. One of these is the present valley of Cedar Creek, which was probably part of an original ice-filled trough that included the basin of Cedar Bog Lake. It is unlikely that the Cedar Bog Lake basin had reached its present size at the time a large meltwater stream was flowing in the Isanti channel. The radiocarbon date of the basal organic deposits of Cedar Bog Lake (11,800 ± 200 years BP) compares well with dates from a site near Loring Park in Minneapolis (11,790 ± 200 (W-454) and 10,200 ± 300 (W-445) (Rubin and Alexander, 1958)) where, according to Cooper and Foot (1932), the deposits correlate with an early stage of the Mississippi River valley train. The radiocarbon dates thus support the inference that Cedar Bog Lake did not form until sometime after the main episode of drainage through the Isanti outwash channel.

Two later events are recorded by prominent geomorphic features on the map, figure 13. The Oxford outwash plain was truncated by the St. Croix River when it carried meltwater from glacial lakes to the north and built a broad terrace. The present course of the Rum River was apparently established after most of the buried ice beneath

the Bethel outwash plain had melted, as the river follows a series of depressions at right angles to the trend of the drainage on the outwash plain.

The present evidence, including the available radiocarbon dates and the correlation of the pollen diagrams, thus suggests that major changes in the landscape were taking place at the time that organic sediment, including pollen, was accumulating at Horseshoe Lake and the North Branch site. More important than these to the development of the vegetation, however, were probably the local changes due to the melting of buried ice blocks. The instability of the landscape that resulted from both the shifting of meltwater streams and the melting of buried ice must have affected the composition and distribution of the vegetation. Perhaps it played a role similar to that played by fire and windthrow in postglacial stable communities, by creating openings and new areas of mineral soil in closed stands. The magnitude of the effect is open to speculation, but the amount of buried ice present in the area under consideration suggests that it may have been large.

Another factor closely related to the evolution of the landscape is movement of the water table. During and immediately after deposition of the outwash plains, of course, the water table was essentially at the surface. Lowering of the water table by surface drainage must have been slow until the present streams (for example, the Rum and St. Croix Rivers) cut into the landscape. The melting of buried ice masses, however, may have had an important effect on the groundwater level because of the volume reduction accompanying the melting. Thus the water table must have remained close to the soil surface, except near subsiding kettles, for some time after above-ground

ice in the vicinity melted away. The ready availability of soil moisture was undoubtedly a significant factor in the environment of the early vegetation.

There is no indication in the present landscape that permafrost ever existed on the Anoka Sand Plain. Involutions found at the North Branch site were believed at first to be evidence of the existence of permafrost, but pollen analysis and radiocarbon dating of the involuted layers indicate a time and climate (post Wisconsin) incompatible with the presence of permanently frozen ground (Fries and others, 1961). It seems probable that the ground beneath the Grantsburg sublobe was not frozen, and there is no reason to believe that it or the deposits on it became permanently frozen after the ice melted.

Similarly, definite geologic evidence for other periglacial processes is lacking. Although sand dunes are locally present on the Anoka Sand Plain (Cooper, 1935), their age is unknown and it is not at all certain that they resulted from periglacial wind activity. Their morphology and distribution indicate formation by winds from the southwest, which is the prevailing wind direction at present.

The physiographic setting for the late-Wisconsin vegetation in the area of Horseshoe and Cedar Bog Lakes, then, was one of low relief. Surface instability resulted first from the shifting of meltwater streams and later from the melting of buried ice masses. Areas where water stood above the mineral-soil surface may have been abundant, and elsewhere the water table could not have been far below the surface. Whether or not vegetation grew upon the glacier surface is here a moot question, because of the difficulty of defining and locating the edge of an ice sheet wasting by downmelting. Certainly plants grew above glacial ice, however, and an estimate of the time

during which they did is given by the correlation of pollen profiles and radiocarbon dates from the North Branch buried peat, Horseshoe Lake, and Cedar Bog Lake; the dates suggest that the time may have been as long as 1000 years.

Significance of the pollen record

In the interpretation of one or more pollen diagrams from a limited area, as in the study of the living vegetation of any area, two approaches are possible: the floristic and the vegetational. Both approaches are useful and each has its peculiar advantages, but the reconstruction of either flora or vegetation from a pollen-stratigraphic record is full of difficulties. The compilation of a list of the species present in the past flora of an area is severely limited by the incompleteness of the fossil record. The majority of the plant species likely to be present in the vegetation at any time disperse so little pollen that the probability of finding even a single grain of any of them is low indeed. Furthermore, the limitations set by pollen morphology often make impossible the identification to the low taxonomic level demanded by careful floristic analysis. It is here that study of macrofossils--that is, plant parts other than pollen and spores--is most valuable, for it greatly increases the chances of specific determinations. Yet even after many millions of pollen grains and countless macrofossils have been recovered and identified the floral list is doomed to contain gaps, particularly in certain groups (for example the Gramineae, whose pollen grains, although common, are nearly indistinguishable, and whose floral parts and seeds are apparently rarely preserved).

The advantage of the floristic approach to pollen analysis is due to the similarity of the principles that underlie the two disciplines. The floristic analysis of a given region is, like pollen analysis, concerned with an integration of the plant species in that region, rather than with the way the species are distributed or segregated. On the other hand, the information derived from pollen spectra is not confined to a definite region: in pollen analysis the area of integration is limited only by the tenuous bounds of probability.

Besides information about the flora of an area, pollen analysis offers data relevant to the reconstruction of the vegetation. These are the numerical data that result from a count of the pollen types present in a sample of sediment. Presumably there exists some unknown functional relationship between the number of pollen grains of a given taxon deposited in the sediment and the number of individuals of that taxon surrounding the site of deposition. The function is undoubtedly complex and contains a number of independent variables such as the ecological factors affecting pollen production and dispersal by the individual plant, wind velocity, and physical and chemical conditions at the site of deposition. It is widely believed, however, that the abundance of the taxon in the surrounding vegetation is the dominant variable, and gross changes in the numbers of pollen grains (commonly expressed as relative frequency) in a sediment are normally interpreted as indicating corresponding shifts in the composition of the vegetation. Because a pollen spectrum yields no information about the composition or distribution of the plant communities that make up the vegetation, the reconstruction of the vegetation must

remain a problem to be solved by inference, aided by thorough knowledge of modern plant communities and the pollen rain they produce.

Thus a pollen diagram is to be thought of as a direct record of neither flora nor vegetation; it contains hints of both but is different from either. Like floral or vegetational units, pollen spectra are mappable, but they are a different kind of unit. For a pollen spectrum exists only at a point--an infinitesimal area of sediment surface--compared with the area occupied by a plant community or a floristic province, and the pollen spectrum owes its character to conditions in an unbounded area outside that infinitesimal area where it is found, rather than being defined strictly by properties within the area where it occurs. It is this deliberate concern with thanatocoenoses rather than biocoenoses that is the peculiarity of pollen analysis, and it is the mappable lateral variation as well as stratigraphic variation of an infinite series of such thanatocoenoses that provides the strength of the discipline.

Pollen flora

Although a list of pollen types drawn from pollen analysis (which may be called a pollen flora) differs in important ways from the floral list of an area of vegetation, it remains useful to examine the affinities of the late-Wisconsin pollen rain to present-day plant distributions. To this end the total number of pollen types found in the Picea-Larix assemblage zone at Horseshoe Lake, Cedar Bog Lake, and Andree Bog are here considered together. Taxa identified from macrofossils at North Branch (Fries and others, 1961) are included; they are indicated in the following lists by an asterisk (*).

The resulting total late-Wisconsin pollen flora is subdivided into a number of floristic elements defined by present geographical distribution and believed to contain taxa of similar origin. The elements used are similar to those employed by Dansereau (1957, p. 48) to characterize the flora of the St. Lawrence basin. Data on the distribution of modern taxa is from a variety of sources, but agrees largely with the range information in Fernald (1950) and Scoggan (1957).

The total number of pollen and spore types identified is 104. Of these, the largest group (33 percent) is classed as a Subcosmopolitan element. It is composed of pollen types derived from taxa whose present ranges include several floristic provinces (in the sense of Good, 1953). The group includes a few species of wide range (for example, Pteridium aquilinum), but most of its members are larger taxa that were not subdivided (for example, Cyperaceae, Salix). The following pollen types are included in this element:

> Sphagnum, Equisetum, Lycopodium complanatum-type, Isoetes, Dryopteris-type, Pteridium aquilinum, Juniperus/Thuja, Typha latifolia, Scheuchzeria, Gramineae, Cyperaceae, Allium, Salix, Populus tremuloides-type, Betula, Urtica-type, Rumex cf. mexicanus, Polygonum amphibium-type, Chenopodium-type, Caryophyllaceae, Nuphar, Ranunculus-type, Thalictrum cf. dasycarpum, Cruciferae, Rosaceae, cf. Sium suave, Umbelliferae undifferentiated, Cornus, Ericaceae-type, Scutellaria cf. epilobiifolia, Dracocephalum-type, Galium, Tubuliflorae undifferentiated, Liguliflorae.

The next largest group (24 percent) consists of taxa with wide ranges of distribution in the deciduous forest of eastern North America. In particular, the plants occur in the Great Lakes province (defined below) but range widely to the south as well. The following pollen types are included in the Deciduous element:

Osmunda cinnamomea, Athyrium felix-femina, Adiantum, Juglans cf. cinerea, Juglans cf. nigra, Carya, Corylus, Ostrya/Carpinus, Quercus, Ulmus, Celtis, Humulus lupulus, Laportea canadensis, cf. Penthorum sedoides, Xanthoxylum americanum, Acer saccharum, Acer saccharinum-type, Acer negundo, Vitis, Tilia americana, Fraxinus pennsylvanica-type, Phlox pilosa-type, Hydrophyllum cf. virginianum, Plantago rugelii, Xanthium.

Four pollen types are from taxa with present ranges in the deciduous forest south of the Great Lakes province. Two of these (Platanus occidentalis and Iva ciliata-type) center in the western part of the deciduous forest and are classed as a Midwestern element. The other two (Castanea, Morus rubra) include the Appalachian mountains as an important part of their ranges and are considered a Midwestern/Appalachian element.

The Great Lakes element contains taxa whose ranges center on the northern part of the deciduous forest; it includes what Curtis (1959) calls the northern hardwoods province in Wisconsin. Six types are assigned to this element:

Taxus canadensis, Pinus strobus-type, Najas flexilis*, Tofieldia glutinosa, Fraxinus nigra-type, Viburnum trilobum.

Another group of taxa contains those widely distributed in the Great Lakes province and northward in the Canadian Boreal province. This Boreal/Great Lakes element includes 16 percent of the pollen types:

Botrychium cf. multifidum, cf. Gymnocarpium, Abies balsamea, Picea, Larix laricina, Pinus banksiana/resinosa-type, Potamogeton zosteriformis*, Calla palustris, Populus balsamifera, Alnus rugosa, Arceuthobium pusillum, Shepherdia canadensis, Myriophyllum exalbescens*, Hippuris vulgaris*, Menyanthes trifoliata*.

The Canadian Boreal element comprises plants whose present ranges center on the northern conifer forest; the majority of them have transcontinental ranges. Five types are assigned to this element:

Sparganium cf. minimum*, Thalictrum confine-type, Elaeagnus commutata, cf. Mertensia paniculata, Plantago major.

Six other pollen types are derived from taxa whose ranges include both the Canadian Boreal province and the Artic-Alpine province to its north. This Arctic-Alpine/Boreal element includes:

Selaginella selaginoides, Botrychium lunaria, Potamogeton cf. alpinus*, Hedysarum, Epilobium, Phacelia cf. franklinii.

The Prairie element includes taxa whose ranges center on the grasslands of central North America. It is represented by five pollen types:

cf. Heuchera richardsonii, Petalostemum candidum-type, Euphorbia sub-gen. Chamaesyce, Iva xanthifolia-type, Ambrosia-type.

One pollen type (Artemisia) is assigned to an Arctic-Alpine/Prairie element, as it includes species that belong to both of these provinces. One species (Sarcobatus vermiculatus) belongs to a Western element.

The most apparent characteristic of the late-Wisconsin pollen flora is the heterogeneity of its present floristic affinities. This observation is reinforced by appraisal of the contribution of the different floristic elements to the pollen sum. In table 2, the sum of the numbers of grains of the pollen types assigned to each element defined above is expressed as a percentage of the total number of pollen grains and spores counted in all spectra of the two named subzones of the Picea-Larix zone at Horseshoe Lake.

The mixture of diverse floristic elements in the late-Wisconsin pollen flora, demonstrated by table 2, has puzzled many pollen stratigraphers who have dealt with late-Wisconsin sediments in eastern North America. Of particular concern is the interpretation to be given

Table 2. Contribution of floristic elements to the late-Wisconsin pollen flora and to the pollen rain at Horseshoe Lake.

Floristic element	Percentage of total pollen flora (four sites)	Percentage of total pollen rain (Horseshoe Lake)	
		Fraxinus subzone	Betula subzone
Arctic-Alpine/Boreal	6	0.03	0.05
Canadian Boreal	5	0.12	0.09
Boreal/Great Lakes	16	51.0	46.6
Great Lakes	6	7.7	4.5
Deciduous	24	6.2	8.6
Midwestern	2	0.10	0.11
Midwestern/Appalachian	2	0.10	0.05
Arctic-Alpine/Prairie	1	6.0	8.7
Prairie	5	3.2	1.1
Western	1	0.03	0.05
Subcosmopolitan	33	25.5	30.2

to the combination of Boreal and Arctic-Alpine elements with Prairie and Deciduous elements. If the pollen flora is regarded as in some degree representative of the composition of the actual late-Wisconsin flora, it is clear that that flora was as complex as any found today. This inference is difficult to reconcile with the notion that the varied geographical affinities of a modern flora are the result of a long history of successive migrations of plant populations with similar origin and geographical continuity. If the latter view is correct, it would not be expected that the initial flora of newly deglaciated terrain would be more complex, in terms of present-day affinities, than the modern vegetation on which those affinities are based.

Several hypotheses have been advanced to explain the floristic heterogeneity of the late-Wisconsin pollen flora. One proposes

that the pollen flora is contaminated by secondary pollen and hence does not represent the actual flora living near the site of deposition. Andersen (1954) was the most persuasive proponent of this hypothesis. He argued a secondary origin for the pollen of trees of the Deciduous element in his Picea-dominated spectra from George Reserve, Michigan. After subtraction of the postulated secondary pollen, he interpreted the spectra remaining as indicating an open spruce parkland. Andersen did not demonstrate a source for the pollen he classed as secondary, however. In the present case, the study of the sediments at Andree Bog makes the hypothesis of secondary origin of any significant part of the pollen flora inapplicable, and it is accordingly rejected.

A second hypothesis attempts to reconcile the mixture of elements in the pollen flora by proposing that all or a part of one group of pollen is far-blown. The hypothesis is usually advanced to explain the presence of pollen of the Deciduous element, by assuming that most of it has been blown in from communities to the south. For example, West (1961, p. 775) suggested that deciduous tree pollen in his zones 1 and 3 derived from habitats "probably quite distant" from the open spruce woodland he visualized around his site in east-central Wisconsin.

At present there are only two possible ways to test the hypothesis of long-distance transport, and both of these yield only negative evidence. One way is to demonstrate the presence in the same stratigraphic position of macrofossils of the taxa whose pollen is suspected of being wind-transported from a great distance. The other possibility is to demonstrate a marked local variation in the amount of pollen of the suspected taxa in correlative sediments. If such a variation occurs without a corresponding fluctuation in the other

pollen percentages (or if it occurs in absolute frequency measured against rate of sedimentation), and if the distance between sediment samples is very small in comparison with the postulated distance of transport, the variation may be assumed to be due to local changes in source. A similar argument may be applied to variations in a stratigraphic sequence at a single station. Unfortunately, however, no limits can be set at present on the amount of variation allowable before the hypothesis of long-distance transport can be rejected with confidence.

Certain pollen types that appear in the late postglacial sediments of Cedar Bog Lake (Ephedra, Sarcobatus vermiculatus, Iva ciliata-type, Morus rubra, and Platanus) are strongly suspected of being far-blown there, on the basis of the high improbability of the occurrence of the plants at the site. All of these types (except Ephedra) occur in small numbers in the Picea-Larix zone as well, and they are equally suspect there. With the addition of Castanea (represented by only a single pollen grain) these types make up the Western, Midwestern, and Midwestern/Appalachian elements, which are minor components of the pollen flora. Of the remainder of the pollen flora, some types can be considered members of the local flora by the application of the tests discussed above. Thus Picea, Larix, and a number of aquatic species are known as macrofossils (Fries and others, 1961). The pollen percentages of Populus balsamifera, P. tremuloides-type, Juniperus/Thuja, and Fraxinus nigra-type are sufficiently variable, both from site to site and in stratigraphic sequence in one diagram, to make the presence of these trees near the sites highly likely. Similarly, Betula, Alnus rugosa, and Salix must have been present at least in the Betula subzone, and the presence of members of the Cyperaceae and Gramineae is scarcely in question. The presence of most of the rest

of the types is open to some doubt if they are considered individually. With the exception of the three minor elements considered above, however, most of the elements in the pollen flora are so large, either in number of types or in total contribution to the pollen rain (table 2) or both, that it is difficult to dispose entirely of them by appealing to the hypothesis of long-distance transport.

A third hypothesis accepts the heterogeneity of the late-Wisconsin pollen flora as indicative of the character of the vegetation. Fries and others (1961), for example, preferred to interpret the late-Wisconsin spectra at North Branch as suggesting a mixture of vegetation types (swamp conifer forest, oak savanna, and prairie) in which all the elements could be represented. Wright and others (1962) have proposed southeastern Manitoba, where prairie, deciduous forest, and boreal forest meet, as the best present-day analogue of the late-Wisconsin flora of southern Minnesota.

The complexity of the late-Wisconsin pollen flora in the Midwest is not without parallels elsewhere, for a mixture of floristic elements (arctic-alpine, sub-arctic, boreal, and steppe) in northern Europe is accepted as a response to the peculiar late-glacial conditions there. In summarizing the late-glacial fossil record in Denmark and in reconstructing the environment it indicates, Iversen (1954) treats each species individually and recognizes that species which today are widely separated existed side-by-side under the special climatic, edaphic, and light conditions of late-glacial time.

It is significant that all of the taxa identified in the pollen flora have wide geographic ranges at present. This fact is suggested at once by the high percentage (both in number of types and in contribution to the pollen rain) reached by elements that include

two or more floristic provinces (the Boreal/Great Lakes element and the Deciduous element). Furthermore, most of the identified taxa can be found either together or in close proximity in the present vegetation. Only four of the taxa (Sarcobatus vermiculatus, Iva ciliata-type, Platanus occidentalis, and Hedysarum) do not now occur within Minnesota, and the two latter are known from just beyond the southern and northern borders respectively of the state.

It is a curious and perhaps significant fact that of the modern pollen diagrams that are available for sites in the Great Lakes area, none shows a late-Wisconsin pollen flora that is appreciably less complex than those of this study. A comparison of the diagrams has already been made (p. 108). The important point here is that, whether or not the pollen zones defined here can be traced for long distances (and they apparently can be through southeastern Minnesota and part of Wisconsin), all of the diagrams (including those of Andersen (1954), Frey (1959), Jelgersma (1962), West (1961), Fries (1962), and Wright and others (1962)) reveal a complex mixture of floristic elements that has defied simple explanation in terms of the modern flora. Those lying appreciably south (Frey, 1959) or north (Fries, 1962) of a general line from central Minnesota to southern Michigan differ most, but they fail to show the relatively simple pollen flora that one might expect if the flora along that general line occupied an ecotone between boreal forest to the north and deciduous forest to the south. The lack of demonstrable end-members of the mixture of floral elements present in late-Wisconsin diagrams suggests that the concept of an orderly clisere at the close of the Wisconsin glaciation (Dansereau, 1957, p. 114; Martin, 1958) may be in error.

Judged solely from the present distribution of the constituent taxa and their relative contribution to the late-Wisconsin pollen rain (table 2), the conclusion seems inescapable that the late-Wisconsin flora has its closest modern analogue in the southern part of the boreal forest, where meet plants having the greatest part of their range either in the boreal forest to the north or the deciduous forest to the south. The third hypothesis is therefore the one preferred here, combined with the hypothesis of long-distance transport for certain taxa. The following pollen grains found in the Picea-Larix zone are here considered to have probably been blown to the sites from some distance: Castanea, Sarcobatus vermiculatus, and Iva ciliata-type. The following group consists of types which may or may not have been far-blown: Pinus, Juglans cinerea-type, Juglans nigra-type, Carya, Celtis, Morus rubra, Platanus occidentalis, Acer saccharum, Acer saccharinum-type, Vitis, and Tilia americana. The criteria used in making these decisions include the present distribution of the taxa, the number of pollen grains found in the Picea-Larix zone, and the behavior of the pollen types in the postglacial zones, particularly in the near-surface sediments of Cedar Bog Lake. The remainder of the taxa in the pollen flora are tentatively considered to have been present on the Anoka Sand Plain during the late-Wisconsin, although a part of the pollen grains of these may have been blown in from outside the area as well.

The presence of the Prairie element should not be overlooked. In fact, the occurrence of moderate amounts of non-arboreal pollen together with high percentages of Picea pollen has dominated most of the interpretation of the late-Wisconsin pollen flora. Two arguments have been advanced to explain the high relative frequency of

herb pollen. The first compares the late-Wisconsin pollen flora with the present spruce parkland or taiga at the northern fringe of the boreal forest in Canada (Andersen, 1954; West, 1961). These authors disposed of the pollen of the southern elements by one of the first two hypotheses considered above (secondary redeposition and long-distance transport respectively). The present study fails to support this interpretation, for no evidence of a surely Arctic-Alpine element has been found; the plants found that do occur north of the treeline are wide-ranging in the boreal forest as well. The second argument is that the aspen parkland, at the present southern border of the boreal forest in Manitoba and Saskatchewan, is the best analogue for the late-Wisconsin flora (Wright and others, 1962). The present evidence favors this second view, which accepts the hypothesis of late-Wisconsin complexity of flora.

A third possible view is that the late-Wisconsin flora was sufficiently different from any existing today that a comparison with modern floral provinces is pointless. At present there is little positive evidence to support such a contention, which is founded on the apparent lack, referred to above, of fossil equivalents to the present vegetation zones. The suggestion is worth keeping in mind, however, for it may prove to be the most valuable premise on which to base an interpretation of the late-Wisconsin vegetation.

Vegetation

The hypothesis here favored to explain the complexity of the late-Wisconsin pollen flora, by accepting it as a reflection of a complex vegetation, makes the reconstruction of that vegetation extremely difficult. For the hypothesis has the corollary that the plant

communities present in the late-Wisconsin may have harbored different associations of species than any to be found today. The concept of the climax (Clements, 1936) as a fixed association of plants towards which vegetational change converges under constant climate has little practical utility in the interpretation of pollen diagrams, which illustrate a constantly changing combination of taxa. Of much greater use is the individualistic concept of the plant community advanced by Gleason (1939) and championed by Curtis (1959), Drury (1956), and others, which recognizes the uniqueness of plant communities in space and time and stresses the behavioral rather than the floristic classification of communities. Thus when it seems certain that the combination of environmental factors and available species in glaciated North America during the late Wisconsin must have differed from any combination known today, it is misleading and illogical to expect that the same plant associations or even formations necessarily existed then as at present. This is not to say that the vegetation in the midcontinent was azonal, as Drury (1956) implies. Had phytogeographers been present during the late Wisconsin they might well have subdivided the vegetation into units or zones based on physiognomy and floristics, but there is no reason to expect that the units they defined would bear much resemblance to the efforts of their modern colleagues.

Even though communities like those of today cannot be inferred a priori from the late-Wisconsin pollen record, a reconstruction of the communities that did exist can be attempted by applying what is known of the ecological preferences and tolerences of the taxa involved. The assumption is commonly made that the morphology and physiology of present species have not changed significantly since at least the last glaciation. If this assumption is justified, then the ecological

requirements of the species should also be the same today as in the late Wisconsin. Caution must be used in applying modern ecological observations to the reconstruction of past vegetation, however. The distinction between ecotypes of species which possess marked ecotypic variation cannot be made from fossil evidence, and it is the ecotype, rather than the morphological species, that is the basic unit within a plant community. Furthermore, deficiencies in the environmental requirements of a certain plant may have been compensated by other factors not now at the same intensity within the range of the species. This latter possibility is a grave source of danger in the interpretation of late-Wisconsin pollen diagrams, since it must be considered probable that both climate and soil were radically different from present conditions, and since it is just those differences that are of greatest interest.

The attempt to group the late-Wisconsin pollen types into communities that presumably existed near the site of deposition is further hindered by the broad ecological amplitude of some species. The common conifer species Picea mariana, Picea glauca, Larix laricina, Abies balsamea, and Thuja occidentalis, all of which may have been present in the late-Wisconsin vegetation and which together made up the bulk of the pollen rain, can be found in a variety of habitats ranging from swamp or bog to dry upland. From the pollen spectra alone no deduction can be made about which habitat was the most important site for each of the species. For information about the habitats available one must turn to the minor components of the pollen flora and attempt to find taxa whose present environmental requirements are restricted.

The clearest indications are of soil moisture, as information about the distribution of many of the taxa along the soil-moisture gradient is readily available (for example in Curtis (1959), Maycock and Curtis (1960), Rowe (1956), and Bakuzis and Hansen (1959, 1960, 1962a, 1962b). The presence of a wide range of species, from those that are restricted to wet habitats to those found today only on xeric sites, strongly suggests that a full complement of soil-moisture conditions were available during the deposition of the Picea-Larix zone. Typical indicators of wet to wet-mesic habitats are Calla palustris, Tofieldia glutinosa, Alnus rugosa, Penthorum sedoides, Sium suave, Menyanthes trifoliata, and Scutellaria epilobiifolia. On wet-mesic to mesic sites such plants may have occurred as Gymnocarpium dryopteris, Adiantum pedatum, Taxus canadensis, Urtica sp., Laportea canadensis, Thalictrum dasycarpum, Fraxinus nigra, Hydrophyllum virginianum, Mertensia paniculata, and Plantago major. Plants that suggest dry, well-drained soils include Lycopodium complanatum, Heuchera richardsonii, Hedysarum alpinum var. americanum, Elaeagnus commutata, Shepherdia canadensis, and Artemisia sp.

An equally wide range of light conditions must have prevailed. Among the heliophytes may be included Pteridium aquilinum, Tofieldia glutinosa, Petalostemum candidum, Elaeagnus commutata, Sium suave, Plantago major, Artemisia sp., and Ambrosia sp. Sciophytes are represented by Adiantum pedatum, Laportea canadensis, and Hydrophyllum virginianum.

When these habitat indications are combined with the inferences already made about the late-Wisconsin topography, a picture begins to emerge of the landscape in the Horseshoe Lake-Cedar Bog Lake vicinity during the late Wisconsin. The gently rolling surface of the

outwash plains was covered with a mosaic of plant communities ranging from wet, open meadows through forested lowlands and slopes to dry openings on the best-drained sites. The vegetation pattern shifted with time as buried ice masses melted and shallow depressions deepened, drained, or were filled in and invaded by new species. Conifers (Picea mariana and Picea glauca?, Larix, Thuja?, and Abies) occupied the moist areas, together with Fraxinus nigra, which may have thrived under the combined influence of high soil moisture and readily available mineral nutrients. Populus balsamifera and Populus tremuloides may have occupied large areas of the better-drained soils, in stands bordered on one side by the more mesic conifer-hardwood forest and on the other by prairie grassland with Artemisia and Ambrosia species.

Problems in the reconstruction

Three critical problems connected with the interpretation just advanced remain largely unsolved. The first concerns the apparent stability of the vegetation over a period of as much as 1500 years. In an area like the Anoka Sand Plain where relief is low and physiographic and edaphic variation is small, how can the persistence of openings in the forest and the relative importance of Populus species be explained? Perhaps the answer lies in the recurrence of fire or in grazing pressure by herbivores; but the present evidence does not support these or any other alternative.

The second problem is more vexing. How can the virtual absence of pollen of Pinus in the Picea-Larix zone be explained? In earlier interpretations (for example, Potzger, 1946) the absence of pine pollen in the spruce-dominated basal zone of midwestern diagrams, together with its rise to dominance in the succeeding zone, was

considered to be a logical result of a climsere from spruce forest to pine forest to deciduous forest. Later explanations (for example, Andersen, 1954; West, 1961) stressed the presence of non-arboreal pollen in the spruce-dominated zone and, as we have seen, added taiga or spruce woodland to the climsere as the earliest stage. The present evidence makes these positions untenable. Furthermore, even if much of the pollen of the present deciduous element in the Picea-Larix zone is considered to be far-blown from the south, the problem of the low relative pollen frequency of Pinus, which is widely considered to a highly effective pollen producer and disseminator, is unexplained.

If the reconstruction of the late-Wisconsin landscape here attempted is valid, it is inconceivable that habitats suitable for the germination, growth, and flowering of Pinus species were not available. The pine species presumably most readily available (Pinus banksiana, P. resinosa, and P. strobus) all tolerate a broad variation in soil moisture and edaphic conditions. To postulate limiting biotic factors, such as the absence of mycorhizal fungi or the presence of blights or rusts, at best only shifts the problem to another organism. The argument that pine was delayed in reaching the newly deglaciated areas is unsatisfactory because there is no apparent reason why pine should have a lower migration rate than spruce or many of the other plants presumed to have been present.

Unfortunately too little is known of the climatic requirements of the Pinus species to permit a precise evaluation of the possibility that climate limited the expansion of pines during the time represented by the Picea-Larix zone. Although the present range of Pinus banksiana nearly coincides with that of Picea mariana and Picea glauca, which suggests that the three species share nearly the same

climatic requirements, it is altogether possible that the climate during the late Wisconsin was different from any known today in some respect critical to pine but not to spruce. For example, it might be imagined that the late-Wisconsin summer temperature was both lower and more equable than that existing today within the range of Pinus. Such a temperature distribution might be favorable for spruce and many deciduous taxa and yet fail to reach some unknown temperature minimum necessary for the completion of the life cycle of pine. It seems reasonable, in fact, to ascribe many of the floristic peculiarities of the late-Wisconsin pollen spectra to a peculiar (because unknown) climate, in which the annual, seasonal, and even diurnal distribution of temperature, precipitation, and wind velocity were different from the present, although the annual means of these factors need not have been radically different. Testing this suggestion may be possible when more is learned about climatic requirements (and their ecological interactions) for the species involved, and when sufficient studies have been made, particularly near the glacial border, to permit the construction of accurate paleo-distribution maps of the components of the pollen flora. Until then the problem remains tantalizing but insolvable.

The third problem, closely related to the preceding one, is to explain the changes that occur in the pollen diagrams both within and at the end of the Picea-Larix zone. Because neither the vegetation nor the prevailing climate is well understood, interpretation of fluctuations of the pollen curves must remain speculative. Four specific changes will be considered here. The first is the distinctive fluctuations at the base of the Horseshoe Lake diagram (fig. 10). The basal spectrum is in the litter horizon and has already been interpreted

as representing a local sedge meadow that occupied the site before buried ice melted away to form the lake basin. Immediately above it, in the basal lake sediments, are peaks in Betula, Artemisia, and Urtica and, to a lesser extent, Ambrosia and Salix. These are interpreted as the reflection of a local succession on the shores and banks of the newly forming basin, with Artemisia and Ambrosia on the well-drained bare slopes and Salix, Betula (B. pumila?), and Urtica on the moist shores. If this interpretation is correct, the fluctuation is purely a local event, and its use in correlating Horseshoe Lake with the North Branch buried peat (p. 109) is of doubtful value. A similar interpretation based on local physiographic changes could be advanced to explain the prominent peaks of Fraxinus and Populus pollen immediately above the litter horizon at Cedar Bog Lake (fig. 3).

The fluctuations in the relative frequency of Picea pollen throughout the Picea-Larix zone are here considered to have little regional significance. Although it may be possible to match the maxima and minima of the spruce curve among the various diagrams in southeastern Minnesota, the comparison is imperfect, nor is it strengthened by similar variation in the curves of other taxa. The fluctuations result more likely from local changes in the plant communities or in pollen production than from regional climatic changes.

The differences between the two defined subzones of the Picea-Larix zone, however, are more important. Not only can they be more consistently traced in the available pollen diagrams, but the change from Fraxinus subzone to Betula subzone seems to be part of a progressive change in the pollen rain.

On first consideration it may appear that local influences are the cause of the separation of the Betula subzone from the Fraxinus

subzone. The Betula subzone is marked by a rise in both Salix and Alnus, by a greater abundance of Sphagnum spores and by changes in the aquatic components (from Potamogeton dominance to a richer pollen flora with Nuphar, Myriophyllum and others, at Horseshoe Lake). These changes could be interpreted as a succession around the margin of the lake concomitant with a decrease in water depth; indeed, such an explanation is the most reasonable one. But that the change affected not only isolated basins but the entire region is suggested by the regional occurrence of the subzone and the correspondence of the local pollen types with a gradual increase in the Betula percentages. The increase in Betula pollen may, of course, be attributed to the spread of local bog birch (Betula pumila), but its culmination at or very near the end of the Picea-Larix zone strongly suggests that a tree birch (Betula papyrifera?) that took part in the forest succession was the species present. If this is so, then the rise of the Betula curve that marks the beginning of the Betula subzone may reflect a climatic change that was also responsible for the initiation of hydrarch succession over the whole region. The nature of the suggested change is uncertain; most reasonably it was an increase in temperature, a decrease in precipitation, or a seasonal redistribution of either or both of these factors.

The abrupt change in pollen dominance from Picea to Pinus at the end of the Picea-Larix zone was almost certainly climatically determined. Not only Picea, but also Larix, Populus balsamifera, Juniperus/Thuja, and (somewhat later) Abies balsamea decrease sharply in relative frequency in the pollen diagrams. The pollen of certain deciduous trees increases in importance together with pine; these trees are Acer saccharum, Juglans cf. cinerea, Carya, Tilia, and

Platanus. This prominent change in the pollen flora suggests a general rise in temperature, expressed probably as an increase in summer temperature.

The actual mechanics of the vegetational change are less certain. Wright and others (1962) explain the striking succession of peaks in the curves for Picea, Betula (and Alnus), Pinus, Ulmus, and Quercus at Kirchner Marsh, Lake Carlson, and Madelia as reflecting the successive arrival of these trees by migration. This explanation is attractive especially when applied to Pinus, for it at once explains the virtual absence of pine pollen in the Picea-Larix zone and its sudden rise to dominance shortly after the decline of Picea. The absence of a rise in Pinus pollen at Madelia is also logically explained by assuming that pine migrated into the area from the northeast, and was not able to reach Madelia while the climate there was still favorable for it. The idea receives support from the available radiocarbon dates (fig. 12), which suggest that the Pinus-Pteridium zone is younger to the south, and by the development of a new pollen zone (the Betula-Abies zone) at the close of the Picea-Larix zone in the southern diagrams.

The hypothesis of differential migrations rates, however, fails to explain adequately the fact that, with the exception of the absence of pine at Madelia, the order of the peaks is the same in all the diagrams from southeastern Minnesota: namely, Picea, Betula, (Alnus), Pinus, Ulmus, and Quercus. Furthermore, the time of occurrence of these, like the pine maximum, is apparently younger in the southern diagrams than in the northern ones (fig. 12). It calls for too great a coincidence to postulate that all of these trees migrated in the same direction (from northeast to southwest) and at the same rate, and

that they therefore arrived at each site in the same order. Moreover, it seems likely that some of them (Betula, Alnus, Ulmus, and Quercus) were probably already present at or very near the sites long before their pollen curves reach maxima. The final decline of Picea (that is, the end of the Picea-Larix zone) apparently also occurred as much as 1000 radiocarbon years later at Madelia and Kirchner Marsh than at Cedar Bog Lake. This result is unexpected and suggests either that the radiocarbon dates are in error or that some unknown factor (a climatic gradient?) operated to permit the continued presence of Picea in southern Minnesota for some time after it was replaced on the Anoka Sand Plain. Like the preceding problems, this one must remain unsolved at present.

LATE-WISCONSIN CLIMATE AND CHRONOLOGY IN EAST-CENTRAL MINNESOTA

Too little is understood of the composition and distribution of the vegetation on the Anoka Sand Plain after the wastage of the Grantsburg sublobe to permit a precise evaluation of the climate and its changes. Only a few generalizations are possible.

The earliest pollen records on the Anoka Sand Plain, at the North Branch site and Horseshoe Lake, suggest a mild climate at the time the basins formed, probably not long after the deposition of the Oxford outwash plain. The seasonal pattern of temperature and precipitation may have been radically different from that in mid-continental North America at present, and, if so, average annual figures would have little significance. Wright and others (1962) suggest southwestern Manitoba as a modern climatic analogue for the late Wisconsin, and the present study supports the analogy to the extent that the late-Wisconsin mean annual temperature was probably not appreciably lower, nor the precipitation higher, than in northwestern Minnesota or southern Manitoba today. Summer temperatures may have been less than in that area today, however, perhaps by as much as 5°C, provided that the summer temperatures were more equable and the length of the frost-free period no shorter than at present. Summer precipitation must have been low, probably lower than in southwest Manitoba today if the summer temperature was lower, to account for the presence of xeric habitats.

The concept of a mild climate within 100 miles of the late-Wisconsin ice border, while it conflicts with the reconstructions of Martin (1958a), agrees with recent reports of temperate mollusks in

ice-contact lake deposits in North Dakota (Clayton, 1961; Tuthill, 1961). Late-Wisconsin temperatures in mid-continental North America (about latitude 45° N) clearly were higher than has been generally realized heretofore.

The only change within the Picea-Larix zone in southeastern Minnesota here believed to have regional climatic significance is the shift from the Fraxinus to the Betula subzone. This change is interpreted as a gradual increase in temperature that continued through the Pinus-Pteridium zone and into the post-Wisconsin. It is possible but not necessary that the rate of this warming trend increased sharply at the time of the Picea-Larix to Pinus-Pteridium zone transition. The temperature increase probably affected the summer temperature more than the winter; it may have been accompanied by an increase in the amplitude of seasonal and diurnal temperature fluctuations; and the mean annual temperature may not have increased greatly at first.

Although the radiocarbon chronology (fig. 12) indicates that the time of the Valders readvance (dated at about 11,800 radiocarbon years BP in its type area (Broecker and Farrand, 1963)) is included in at least the pollen diagram from Horseshoe Lake, there is no indication of a climatic change to correspond with the readvance of the ice. This is surprising, as it is nearly certain that ice was still active in one or more readvances in northern Minnesota during the period represented in the diagrams. Wright (1962; Wright and others, 1962) has interpreted the upper part of the Betula subzone of the Picea-Larix zone at Kirchner Marsh and Madelia as indicating a cooler climate correlative with the Valders advance. The present interpretation regards this part of the pollen diagrams as indicating a warmer, rather than a cooler, climate than before. If the model of the vegetation proposed

here is sound, a temperature decrease would have resulted in an expansion of spruce forest by the encroachment of that forest on the drier sites occupied by Populus and grassland. The pollen diagram should then record an increase in Picea pollen and a decrease in non-arboreal pollen, including Artemisia. The climatic oscillation postulated by Wright is, however, based primarily on an increase in Artemisia pollen, which is not convincing in the diagrams presented in this study.

The conclusion that there is no evidence in the pollen diagrams for a climatic oscillation contemporaneous with the Valders glacial readvance contradicts the widespread assumption that such a climatic oscillation must have occurred. There are three alternative explanations for the contradiction that seem reasonable: (1) a climatic oscillation occurred but did not extend to east-central Minnesota and affect the vegetation there markedly, (2) a climatic oscillation occurred but affected only parameters (for example, winter precipitation) to which the pollen rain was relative insensitive, (3) there was no climatic oscillation, that is, the fluctuation of the ice-sheet margin was neither dependent upon, nor caused, a cooling of climate.

A climatic oscillation during the time span represented in the Minnesota diagrams is suggested by pollen diagrams from other parts of North America, notably in New England and the Maritime Provinces (Davis, 1961b; Livingstone and Livingstone, 1958; Ogden, 1963; and other papers cited therein), but if it occurred in Minnesota it either was too slight to affect the pollen rain (alternative 1) or was expressed in a way that did not affect the pollen rain (alternative 2). Of course it is possible that it is recorded in the Minnesota diagrams but is here misinterpreted as a minor fluctuation of no regional significance; if this is true the examination of future pollen diagrams from the area should reveal the same fluctuation consistently.

The fluctuations that West (1961) reports in a diagram from a site only 10 miles from the type Valders drift border in Wisconsin are of great interest here. The present interpretation differs from West's, and would consider his zone 3, with increased relative frequency of Ulmus, Fraxinus, Ostrya/Carpinus, and Artemisia pollen, as suggestive of a warmer and drier interval instead of a cooler one (which West correlates with the Valders ice readvance). West's diagram, however, does suggest a climatic oscillation that is not clearly defined in the Minnesota diagrams. Since Horseshoe Lake is about 55 miles south of the drift border presently correlated with the Valders drift in Wisconsin (Wright, 1962), the difference in the diagrams may be partly due to the difference in distance from the ice sheet.

The third alternative given above deserves consideration. A common and often tacit assumption among Pleistocene pollen stratigraphers is that climatic change and movement of the Pleistocene ice sheet margin were closely related in time. Such an assumption is probably based on the recorded sensitivity of modern valley glaciers to measurable changes of climate. The assumption may not be justified, however, when applied to an ice sheet several orders of magnitude larger in areal extent and volume. Although it is probable that such a mass of ice retains a high sensitivity to changes in accumulation and ablation rates (Nye, 1960)--and is perhaps even more sensitive to climate than the vegetation beyond the ice border--it is by no means certain that the movements of the ice margin were in phase with the climatic cycles that caused them. Indeed, the time lag conceivably was great enough to be within the power of radiocarbon dating to determine it. Furthermore, according to the mathematical models of Nye (1960) and Weertman (1961) it may be theoretically possible that

readvance of the margin of a large, rapidly wasting ice sheet could result with no climatic change necessary.

Neither is it clear to what extent the ice sheet affected the climate of the area surrounding its margin. The causal and temporal relationship between climatic change and ice-sheet fluctuation is, of course, a basic and critical problem of Pleistocene study, and to assume a certain relationship when interpreting data pertinent to only one aspect of the problem is to employ a circularity of reasoning that can only lead to confusion.

If it is to be successful as a method of Pleistocene research, pollen analysis must be able to supply data and permit inferences that are independent of other means of inquiry. The present study has attempted such an independence. The extent to which it has redefined the problems within its areal and stratigraphic limitations is the measure of its success.

Table 3. Pollen and spore counts from Cedar Bog Lake.

CEDAR BOG LAKE
Anoka Co., Minn.
E.J. Cushing
1959-1962

Sample no.	D1716	D1736	C1544	C1552	C1560	C1568	C1575	C1583	B1791	B1799	B1807	B1610	B1618	B1626	B1634	B1642	B1650	B1658	B1666	B1674	B1682	A1403	A1411	A1419	A1427	A1435	A1438	A1446	A1454	A1461	A1467	A1474	A1481	A1488	A1496	A1504	A1512	A1519	A1523	A1526	A1531	A1534	A1537	A1539
Depth (cm)	130	150	190	230	270	310	350	390	403	430	470	510	550	590	630	670	710	750	790	830	870	910	950	990	1030	1070	1110	1150	1190	1230	1270	1308	1347	1387	1427	1467	1507	1547	1567	1587	1617	1637	1657	1664
Sphagnum	--	1	1	--	--	2	--	1	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Equisetum	--	--	--	--	1	1	--	1	--	1	1	1	--	1	1	--	--	2	1	8	6	--	2	--	1	--	--	2	--	--	--	--	--	2	1	3	5	5	7	2	--	--	--	--
Lycopodium selago-type	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lycopodium complanatum-type	1	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lycopodium undifferentiated	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	--	--	--	1	2	--	--	--	--	--	--	--	--	--
Selaginella	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Osmunda	1	1	2	--	3	3	2	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3
Dryopteris-type	15	9	2	1	2	--	1	1	--	1	3	--	5	6	8	18	11	13	30	43	48	62	153	78	21	37	5	44	11	7	6	5	6	6	7	3	4	--	2	1	2	3	4	--
Pteridium aquilinum	4	3	--	--	2	--	--	--	--	1	1	--	--	--	1	2	1	2	4	11	--	5	14	3	7	2	5	6	3	3	5	6	20	18	9	8	--	--	6	5	5	2	2	--
Ephedra trifurca-type	--	--	--	--	1	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--
Ephedra viridis-type	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ephedra undifferentiated	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Abies balsamea	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--
Tsuga	--	3	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--	1	3	2	--	1	1	1	--	--	1	1	1	1	3	8	5	8	11	20	--	1	--	--	--
Picea	1	--	1	--	3	--	--	2	--	1	1	1	1	--	--	1	--	1	--	1	16	6	24	--	14	12	11	16	1	1	1	1	2	5	4	76	154	222	295	217	193	258	151	202
Larix laricina	11	26	17	16	21	48	15	22	10	5	--	--	--	1	--	--	1	--	1	1	2	2	4	--	2	1	--	1	4	1	1	1	6	4	3	10	10	16	23	23	1	6	7	--
Pinus strobus-type	--	9	13	4	3	10	3	1	4	3	10	4	1	7	not differentiated																														
Pinus banksiana/resinosa type	15	1	2	2	4	2	2	7	5	4	2	2	2	2	not differentiated																												
Pinus undifferentiated	21	70	39	28	32	56	23	18	10	17	55	20	25	26	78	71	51	34	75	116	138	100	193	66	119	111	68	116	126	69	192	166	312	268	191	183	9	8	11	11	4	19	3	4
Juniperus/Thuja	7	8	15	9	3	4	3	6	8	5	3	7	10	11	1	--	--	--	--	7	--	2	--	1	6	2	--	5	6	--	--	--	1	2	1	3	1	16	24	6	--	--	--	--
Typha latifolia	2	1	--	--	--	--	1	--	--	--	1	--	2	1	2	3	1	2	2	4	5	2	3	7	1	11	1	5	2	--	2	1	4	1	1	4	5	4	8	4	4	5	--	--
Sparganium-type	1	--	--	--	--	--	1	--	1	--	--	--	1	--	1	1	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Potamogeton (Eupotamogeton)	3	1	--	--	2	3	3	--	2	2	9	4	1	--	--	--	--	--	1	4	1	--	1	--	8	1	2	1	4	4	--	--	--	--	--	--	2	--	2	3	5	2	--	3	1
Scheuchzeria	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sagittaria	--	--	--	--	--	--	--	1	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--
Gramineae	164	342	331	199	224	520	653	197	148	76	76	49	72	62	195	198	68	42	63	145	39	25	50	22	124	86	34	113	95	38	46	41	23	23	10	8	11	28	41	17	24	8	9	1
Cerealia	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cyperaceae	5	16	7	14	19	23	11	14	17	19	116	34	42	27	31	42	14	29	45	84	30	23	46	38	61	53	14	61	71	39	44	14	22	26	18	20	60	35	78	44	37	25	33	4
Salix	2	2	1	1	2	2	--	4	--	3	7	1	4	--	4	5	1	--	2	9	1	2	4	4	15	4	4	5	3	4	10	3	4	2	2	6	10	24	31	10	8	6	1	--
Populus	6	8	1	3	2	5	1	5	1	--	1	--	--	--	3	5	--	1	10	13	3	1	2	2	19	15	6	13	24	6	8	3	12	18	25	14	20	12	13	15	17	16	39	1
Juglans cf. cinerea	--	1	--	2	--	4	2	2	--	--	--	--	--	1	1	--	--	1	1	--	2	--	1	--	2	1	--	3	7	1	--	--	3	4	5	1	--	--	--	--	1	--	--	--
Juglans cf. nigra	1	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	1	--	--																					
Carya	1	1	1	--	2	2	1	1	--	--	--	1	--	--	--	1	--	1	1	4	1	4	4	--	--	1	1	4	3	5	4	--	1	--	5	1	--	--	--	--	--	1	--	--
Corylus	1	4	--	--	3	3	10	1	2	2	2	3	3	2	2	2	1	--	2	5	1	2	5	2	18	3	5	9	3	3	3	5	4	9	6	15	7	1	7	10	8	11	3	--
Ostrya/Carpinus	9	7	9	5	9	40	27	39	15	14	6	7	6	6	13	27	3	6	10	20	10	2	1	--	9	14	4	15	12	16	11	14	11	6	17	13	10	5	18	12	16	10	4	--
Betula	44	77	39	28	28	82	16	15	9	8	11	6	7	2	7	15	5	8	6	12	6	7	14	4	21	14	4	17	5	13	23	11	30	20	109	91	70	54	74	23	30	35	1	--
Alnus	14	25	12	13	21	26	19	14	11	13	11	3	5	6	11	13	1	6	3	12	7	2	5	1	10	9	2	13	29	18	19	9	25	10	17	34	55	14	19	8	4	1	--	1
Quercus	66	96	71	98	117	224	67	67	58	79	71	53	50	41	92	123	55	68	119	195	42	39	69	16	149	85	26	138	63	40	83	34	63	38	35	39	11	13	44	22	34	27	20	11
Ulmus	8	17	2	4	3	18	13	10	3	5	11	5	15	11	28	39	9	7	17	29	16	8	16	1	33	44	5	89	47	29	28	45	63	52	60	29	18	7	12	9	2	6	2	1
Celtis occidentalis	--	--	1	--	--	1	--	2	--	2	--	4	1	1	4	1	1	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Morus rubra	--	--	--	--	--	--	--	--	--	--	1	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
cf. Cannabis sativa	2	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Humulus lupulus	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Urtica-type	4	1	1	--	1	--	2	1	2	--	1	1	2	--	2	1	--	--	--	2	--	--	--	--	1	--	--	--	--	--	1	--	--	1	--	--	3	2	--	--	--	--	--	--
Laportea-type	--	--	--	--	--	--	--	--	1	3	--	1	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pilea-type	--	--	--	--	--	--	--	--	1	11	12	1	1	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rumex cf. maritimus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rumex undifferentiated	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Polygonum amphibium-type	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--
Polygonum lapathifolium-type	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chenopodium-type	22	14	1	2	1	8	5	9	5	5	9	16	22	10	12	14	11	10	16	29	6	4	10	13	38	25	6	31	16	13	12	7	6	2	5	5	3	5	8	3	8	11	3	--
Salsola kali	3	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sarcobatus vermiculatus	--	--	2	2	--	1	--	--	--	--	2	--	1	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Caryophyllaceae	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nuphar	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	--	--	4	1	2	--	--	1	--	--	--	--	--	--	1	--	3	1	--	4	2	--	--	--	--	--	--
Nymphaea	--	1	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Thalictrum	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--	1	2	--	--	--	--	1	--	1	--	2	--	--	--	1	--	--	--	1	--	--	--	1	1	--
Caltha-type	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
cf. Brassica	1	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cruciferae undifferentiated	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Platanus occidentalis	--	1	1	1	3	3	4	1	1	--	1	1	--	--	1	1	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rosaceae	--	1	--	--	--	--	--	--	--	--	1	--	--	--	2	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	1	--	--	1	--	--
Prosopis cf. pubescens	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Amorpha	--	--	1	1	--	1	1	--	--	--	1	--	1	2	--	2	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Petalostemum candidum-type	--	--	--	--	1	--	--	--	--	1	2	1	3	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Petalostemum purpureum	--	--	--	--	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Leguminosae undifferentiated	1	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Xanthoxylum americanum	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Euphorbia (Chamaesyce)	--	1	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer saccharum	--	4	1	1	2	8	3	2	--	--	--	2	3	1	1	10	3	5	2	13	4	2	6	2	4	1	--	19	6	3	--	1	4	1	2	1	3	3	--	--	1	--	--	--
Acer rubrum	2	--	--	--	--	4	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer saccharinum-type	--	1	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer negundo	--	1	--	--	--	--	--	--	--	--	--	2	--	--	1	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhamnus alnifolia	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Vitis	1	2	--	--	--	--	--	1	--	1	--	1	--	--	--	1	2	2	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tilia americana	3	3	--	2	1	3	5	12	4	4	2	4	4	2	10	25	14	7	11	11	4	1	2	--	--	--	--	2	--	1	1	1	1	--	--	--	--	--	--	--	--	--	--	--
Shepherdia canadensis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--
Decodon verticillatus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	2	--	2	--	--	--	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Epilobium	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--
Myriophyllum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Umbelliferae	1	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	1	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cornus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ericaceae	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--
Fraxinus pennsylvanica-type	2	--	--	--	--	--	2	2	--	--	--	2	--																															
Fraxinus nigra-type	2	7	2	5	3	7	3	4	1	2	4	--	2	1	7	5	--	--	1	--	1	--	2	2	36	12	5	23	9	11	15	15	12	14	29	22	8	19	30	13	27	22	78	3
Menyanthes trifoliata	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Phlox	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Onosmodium	--	--	1	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Galium	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
Viburnum lentago	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Iva ciliata-type	1	--	1	--	1	--	1	--	--	--	1	--	2	--	1	3	--	--	7	9	1	1	4	--	1	not differentiated																			
Iva xanthifolia-type	4	--	1	--	--	1	1	1	1	--	1	--	--	1	--	--	--	--	--	--	--	--	--	--	not differentiated																			
Ambrosia-type	161	82	9	6	8	22	12	16	9	21	29	10	24	16	42	50	17	15	53	125	29	28	58	15	not differentiated																			
Xanthium	1	--	--	--	--	--	1	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	not differentiated																			
Artemisia	7	11	11	7	17	22	15	19	13	10	36	20	74	37	50	97	40	29	50	198	25	13	33	12	194	72	39	78	83	38	48	30	27	9	5	18	36	53	112	44	59	51	14	1
Cirsium	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tubuliflorae undifferentiated	5	4	3	2	6	8	5	11	3	1	15	6	6	2	7	9	4	9	8	26	4	11	3	5	110	55	27	60	41	28	23	13	13	6	5	5	5	10	23	5	21	23	15	9
Liguliflorae	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Unknown	1	3	--	--	--	--	1	--	1	1	1	1	2	1	1	--	--	2	--	--	--	1																							
Indeterminable: deteriorated	4	8	2	1	2	--	1	--	--	1	3	2	1	1	10	8	3	3	2	16	12	11	20	12	13	10	4	12	5	2	5	2	7	2	4	2	3	1	5	5	2	3	--	1
Indeterminable: broken/concealed	4	6	3	--	1	3	6	2	4	3	11	--	6	5	7	8	--	4	4	7	8	8	2	--																				

Table 4. Pollen and spore counts from Andree Bog.

ANDREE BOG
Isanti Co., Minn.
E. J. Cushing
1962

Sample no.	AA79	AA83	AA84	AA86	AA88	AA90	AA92	AA93	AA94	AA95	AA96	AA97	AA98	AA99	AA100	AA101	AA102	AA103	AA172	AA104	AA148	Gray silty till, Elk River
Depth (cm)	425	445	505	515	525	535	545	556	560	565	570	575	580	585	590	595	600	605	609	620	875	005S
Sphagnum	--	--	--	--	--	6	--	2	4	1	1	2	1	1	1	3	--	1	2	--	2	--
Equisetum	--	--	6	29	5	2	--	2	3	1	1	9	4	7	3	2	3	4	1	--	1	--
Lycopodium complanatum-type	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Selaginella	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	3	--
Isoetes	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Botrychium cf. multifidum																						
Botrychium cf. multifidum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
Botrychium lunaria	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--
Osmunda cinnamomea	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--
Dryopteris-type	22	13	14	3	--	3	--	1	1	1	--	3	2	3	4	16	8	5	4	3	4	6
Dryopteris thelypteris	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
cf. Gymnocarpium	--	--	1	--	--	--	--	--	--	--	--	--	--	1	8	1	--	2	1	--	--	--
Athyrium felix-femina	--	--	5	--	1	--	--	--	--	--	--	--	--	1	1	9	--	1	1	--	--	--
Adiantum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
Pteridium aquilinum	10	10	1	--	3	--	--	1	--	--	--	--	--	--	--	2	--	1	--	3	2	--
Taxus canadensis	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--
Abies balsamea	1	2	1	3	--	--	--	--	--	--	--	--	--	1	--	--	--	--	1	--	--	--
Picea	7	7	36	212	222	154	113	111	246	296	162	208	182	398	188	100	190	115	162	85	51	4
Larix laricina	--	3	7	39	23	19	10	11	24	8	11	16	10	13	14	12	7	4	2	8	--	1
Pinus	118	182	119	74	16	4	--	2	3	3	2	1	1	7	1	8	4	6	1	22	64	7
Juniperus/Thuja	11	--	11	19	8	15	7	12	22	5	9	16	16	7	3	5	1	1	2	3	1	5
Typha latifolia	3	1	5	4	3	5	--	3	1	7	4	3	--	--	--	--	--	--	2	2	--	--
Sparganium-type	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Potamogeton (Coleogeton)	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--
Potamogeton (Eupotamogeton)	--	1	1	7	4	9	--	8	12	4	7	15	9	13	8	--	3	1	1	--	1	--
Scheuchzeria	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gramineae	75	18	13	17	17	16	9	17	26	19	16	20	9	15	11	6	11	5	5	11	16	3
Cyperaceae	27	18	14	42	42	44	20	42	49	37	36	45	35	52	41	45	30	62	10	46	39	8
Calla palustris	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Lemna	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Salix	12	4	2	11	7	9	3	3	12	9	3	6	2	5	4	4	1	2	1	2	3	1
Populus tremuloides-type	12	10	4	41	9	12	3	13	3	4	12	1	2	8	2	6	37	1	--	1	2	5
Populus balsamifera	2	4	13	45	24	12	6	10	26	24	11	24	12	6	13	7	8	--	1	1	--	--
Juglans cf. cinerea	1	1	2	2	--	--	1	--	--	--	--	1	--	--	1	--	--	--	--	--	--	--
Juglans cf. nigra	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--
Carya	5	3	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Corylus	7	2	9	12	4	2	1	1	5	3	1	5	--	--	1	--	1	2	--	2	7	5
Ostrya/Carpinus	23	14	5	17	11	8	2	7	9	6	5	17	3	5	4	4	--	3	2	6	8	3
Betula	26	44	72	119	24	19	15	27	22	9	12	3	5	4	3	1	1	--	2	8	7	2
Alnus rugosa	13	19	11	48	16	13	5	16	6	10	1	1	1	--	1	2	--	--	4	1	1	1
Quercus	47	43	9	44	25	11	3	6	7	8	5	21	8	1	3	1	--	1	4	--	3	2
Ulmus	36	48	18	52	14	6	1	10	7	4	1	4	1	1	1	--	--	--	--	1	--	--
Celtis occidentalis	2	--	1	1	1	--	--	--	1	--	--	--	--	--	--	--	1	--	--	--	--	1
Morus rubra	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Humulus lupulus	--	1	--	3	--	--	--	--	2	--	2	3	3	--	2	--	1	--	2	--	--	--
Urtica-type	--	4	2	4	2	3	1	7	12	--	5	3	7	4	4	5	--	--	1	--	--	--
Laportea-type	3	1	--	10	--	2	--	--	2	--	--	--	4	--	--	--	--	--	--	--	--	--
Arceuthobium	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rumex cf. mexicanus	--	--	2	--	1	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Chenopodium-type	20	1	2	9	1	5	1	6	--	2	5	6	4	--	--	1	2	--	--	2	6	1
Sarcobatus vermiculatus	--	--	--	1	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Caryophyllaceae	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Nuphar	1	1	2	1	--	2	1	5	--	--	3	--	--	--	--	--	--	--	--	--	--	--
Nymphaea	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ranunculus-type	--	--	--	--	--	--	--	--	--	--	1	--	3	--	--	--	--	--	--	--	--	--
Thalictrum	--	--	--	2	--	1	--	--	1	--	1	--	1	1	--	--	--	--	--	--	--	--
Cruciferae	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	--	--	--
Rosaceae	--	--	--	3	1	2	--	--	--	1	--	1	--	--	--	--	--	--	--	--	1	--
Petalostemum candidum-type	1	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--
Euphorbia (Chamaesyce)	--	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhus cf. vernix	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer saccharum	4	2	1	2	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer saccharinum-type	2	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer negundo	--	1	--	7	5	1	--	1	2	--	--	--	2	1	--	--	--	--	--	--	--	--
Vitis	1	--	1	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tilia americana	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	--
Shepherdia canadensis	1	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
Myriophyllum exalbescens-type	3	--	--	--	--	--	--	2	--	--	--	--	3	--	--	--	--	--	--	--	--	--
Cornus	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--
Ericaceae-type	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
Fraxinus pennsylvanica-type	4	2	3	5	1	--	--	--	--	--	2	1	1	--	--	--	--	--	--	--	--	--
Fraxinus nigra-type	8	21	29	67	29	9	8	8	16	12	9	54	15	4	6	1	1	1	3	2	2	4
cf. Mertensia paniculata	--	--	--	--	--	--	--	--	1	--	--	--	--	2	--	--	--	--	--	--	--	--
Scutellaria cf. epilobiifolia	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lycopus-type	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Utricularia	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Plantago	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Galium	--	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--
Iva ciliata-type	3	--	--	--	1	--	--	--	--	--	2	--	2	--	--	--	--	--	--	--	--	--
Iva xanthifolia-type	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	1	--	--	--
Ambrosia-type	29	21	1	8	5	5	2	1	4	7	3	8	11	5	3	--	9	2	2	2	3	1
Artemisia	28	7	9	31	19	25	14	16	28	37	27	35	22	10	9	--	6	1	2	1	17	2
Tubuliflorae undifferentiated	12	2	1	2	5	2	3	1	7	6	6	3	4	3	3	6	5	5	--	5	6	1
Liguliflorae	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	1	--
Unknown	1	--	1	--	1	1	--	--	3	3	--	1	2	3	1	--	1	1	1	11	2	3
Indeterminable: deteriorated	6	6	2	2	3	6	3	3	4	33	5	14	10	61	22	72	77	64	12	272	327	281
Indeterminable: broken/concealed	5	12	1	7	3	7	3	7	9	8	12	13	5	1	5	--	--	--	1	2	--	--
Aquilapollinites Rouse	--	--	--	--	--	1	--	--	1	--	--	--	--	--	--	1	--	--	--	--	1	4
Cingutriletes congruens Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	3	1
Cingutriletes densocingulatus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Cingutriletes interruptus Pierce	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	1	--	--	3	9	5
cf. Clavabivesiculites pannosus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	1	--	--
cf. Foveoinaperturites scaphoformis Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Foveotriletes triplanus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
cf. Gemmainaperturites rugosus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Psilatriletes excelsus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	2	--	--	--	2	3	2
Psilatriletes virgus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	1	--	4	4	4

Potamogeton (Coleogeton)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Potamogeton (Eupotamogeton)	--	1	1	7	4	9	--	8	12	4	7	15	9	13	8	--	3	1	1	--	1	--
Scheuchzeria	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gramineae	75	18	13	17	17	16	9	17	26	19	16	20	9	15	11	6	11	5	5	11	16	3
Cyperaceae	27	18	14	42	42	44	20	42	49	37	36	45	35	52	41	45	30	62	10	46	39	8
Calla palustris	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Lemna	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Salix	12	4	2	11	7	9	3	3	12	9	3	6	2	5	4	4	1	2	1	2	3	1
Populus tremuloides-type	12	10	4	41	9	12	3	13	3	4	12	1	2	8	2	6	37	1	--	1	2	5
Populus balsamifera	2	4	13	45	24	12	6	10	26	24	11	24	12	6	13	7	8	--	1	1	--	--
Juglans cf. cinerea	1	1	2	2	--	--	1	--	--	--	--	1	--	--	1	--	--	--	--	--	--	--
Juglans cf. nigra	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--
Carya	5	3	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Corylus	7	2	9	12	4	2	1	1	5	3	1	5	--	--	1	--	1	2	--	2	7	5
Ostrya/Carpinus	23	14	5	17	11	8	2	7	9	6	5	17	3	5	4	4	--	3	2	6	8	3
Betula	26	44	72	119	24	19	15	27	22	9	12	3	5	4	3	1	1	--	2	8	7	2
Alnus rugosa	13	19	11	48	16	13	5	16	6	10	1	1	1	--	--	1	2	--	--	4	1	1
Quercus	47	43	9	44	25	11	3	6	7	8	5	21	8	1	3	1	--	1	4	--	3	2
Ulmus	36	48	18	52	14	6	1	10	7	4	1	4	1	1	1	--	--	--	--	1	--	--
Celtis occidentalis	2	--	1	1	1	--	--	--	1	--	--	--	--	--	--	--	1	--	--	--	--	1
Morus rubra	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Humulus lupulus	--	1	--	3	--	--	--	--	2	--	2	3	3	--	2	--	1	--	2	--	--	--
Urtica-type	--	4	2	4	2	3	1	7	12	--	5	3	7	4	4	5	--	--	1	--	--	--
Laportea-type	3	1	--	10	--	2	--	--	2	--	--	--	4	--	--	--	--	--	--	--	--	--
Arceuthobium	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rumex cf. mexicanus	--	--	2	--	1	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Chenopodium-type	20	1	2	9	1	5	1	6	--	2	5	6	4	--	--	1	2	--	--	2	6	1
Sarcobatus vermiculatus	--	--	--	1	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Caryophyllaceae	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Nuphar	1	1	2	1	--	2	1	5	--	--	3	--	--	--	--	--	--	--	--	--	--	--
Nymphaea	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ranunculus-type	--	--	--	--	--	--	--	--	--	--	--	1	--	3	--	--	--	--	--	--	--	--
Thalictrum	--	--	--	2	--	1	--	--	1	--	1	--	1	1	--	--	--	--	--	--	--	--
Cruciferae	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	--	--
Rosaceae	--	--	--	3	1	2	--	--	--	1	--	1	--	--	--	--	--	--	--	--	1	--
Petalostemum candidum-type	1	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--
Euphorbia (Chamaesyce)	--	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhus cf. vernix	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer saccharum	4	2	1	2	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer saccharinum-type	2	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer negundo	--	1	--	7	5	1	--	1	2	--	--	--	2	1	--	--	--	--	--	--	--	--
Vitis	1	--	1	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tilia americana	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	--
Shepherdia canadensis	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
Myriophyllum exalbescens-type	3	--	--	--	--	--	--	2	--	--	--	--	3	--	--	--	--	--	--	--	--	--
Cornus	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--
Ericaceae-type	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
Fraxinus pennsylvanica-type	4	2	3	5	1	--	--	--	--	--	2	1	1	--	--	--	--	--	--	--	--	--
Fraxinus nigra-type	8	21	29	67	29	9	8	8	16	12	9	54	15	4	6	1	1	1	3	2	2	4
cf. Mertensia paniculata	--	--	--	--	--	--	--	--	1	--	--	--	--	2	--	--	--	--	--	--	--	--
Scutellaria cf. epilobiifolia	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lycopus-type	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Utricularia	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Plantago	1	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Galium	--	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	--	--	--
Iva ciliata-type	3	--	--	--	1	--	--	--	--	--	2	--	2	--	--	--	--	--	--	--	--	--
Iva xanthifolia-type	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	1	--	--	--
Ambrosia-type	29	21	1	8	5	5	2	1	4	7	3	8	11	5	3	--	9	2	2	2	3	1
Artemisia	28	7	9	31	19	25	14	16	28	37	27	35	22	10	9	--	6	1	2	1	17	2
Tubuliflorae undifferentiated	12	2	1	2	5	2	3	1	7	6	6	3	4	3	3	6	5	5	--	5	6	1
Liguliflorae	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	1	--
Unknown	1	--	1	--	1	1	--	--	3	3	--	1	2	3	1	--	1	1	1	11	2	3
Indeterminable: deteriorated	6	6	2	2	3	6	3	3	4	33	5	14	10	61	22	72	77	64	12	272	327	281
Indeterminable: broken/concealed	5	12	1	7	3	7	3	7	9	8	12	13	5	1	5	--	--	--	1	2	--	--
Aquilapollinites Rouse	--	--	--	--	--	1	--	--	1	--	--	--	--	--	--	1	--	--	--	--	1	4
Cingutriletes congruens Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	3	1
Cingutriletes densocingulatus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Cingutriletes interruptus Pierce	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	1	--	--	3	9	5
cf. Clavabivesiculites pannosus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	1	--	--
cf. Foveoinaperturites scaphoformis Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Foveotriletes triplanus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
cf. Gemmainaperturites rugosus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Psilatriletes excelsus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	2	--	--	--	2	3	2
Psilatriletes vitreus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	1	--	4	4	4
Psilatriletes vulgaris Pierce	--	--	--	--	--	--	--	--	--	1	--	--	--	1	1	1	2	4	--	22	28	22
cf. Pterocarya Kunth.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1
Punctamultivesiculites Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--
cf. Punctatisporites punctus Pflug	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
Punctatriletes parvimundus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	--
Retitetradites monocolpatus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	1	3	1	2	3	1	--	12	8	--
Retitricolpites prolatus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	2	--	3
cf. Retitricolpites vulgaris Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--
Rugubivesiculites Pierce	--	--	1	--	--	--	--	1	--	1	--	1	--	4	--	3	1	3	--	15	21	--
cf. Rugulatisporites quintus Pflug & Thomson	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	2	--	3
Rugutriletes regularis Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	1
Striatriletes V. d. Ham.	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	--	4	--	4	4	3
cf. Striatriletes bifurcus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
cf. Triplanosporites Pflug	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	1	--
cf. Verruinaperturites depressus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
cf. Verrumonocolpites conspicuus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--
Verrumonoporites verrucatus Pierce	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	1
Unknown K 7	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	1	--	2	6	--
Unknown K 10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	1	1
Unknown K 26	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
Unknown K 27	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	--	--
Unknown 0121	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
Pre-Quaternary spores and pollen, undifferentiated	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	14
Dinoflagellates + hystrichosphaerids	--	--	--	--	--	1	--	1	--	2	1	--	4	9	6	35	6	6	5	71	158	58

Table 5. Pollen and spore counts from Horseshoe Lake.

HORSESHOE LAKE
Isanti Co., Minn.
E. J. Cushing
1962

Sample no.	HA148	HA152	HA156	HA157	HA159	HA161	HA162	HA163	HA164	HA165	HA166	HA167	HA168	HA169	HA170	HA171	HA172	HA173	HA174	HA175	HA176	HA177	HA178	HA179	HA180	HA181	HA182	HA183	HA184
Depth (cm)	900	920	940	945	960	970	975	980	985	990	995	1000	1005	1010	1015	1020	1025	1030	1035	1040	1045	1055	1060	1065	1070	1075	1080	1085	1090
Sphagnum	--	--	--	--	--	--	4	1	2	2	4	1	2	2	3	3	3	3	3	2	--	--	2	--	--	1	2	--	--
Equisetum	1	1	--	--	--	2	2	2	1	2	2	2	2	7	3	6	--	1	1	3	3	3	5	4	8	12	9	6	4
Lycopodium clavatum	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lycopodium complanatum-type	--	--	--	--	--	1	--	1	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Selaginella selaginoides	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
Botrychium lunaria	--	--	--	--	--	--	--	--	--	--	--	--	?	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dryopteris-type	10	6	8	10	4	11	--	1	1	4	1	--	1	3	5	7	6	8	5	7	9	6	4	5	3	13	3	3	4
cf. Gymnocarpium	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
Athyrium felix-femina	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	1	--	--	--	--	--	--	1
Cryptogramma cf. stelleri	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Adiantum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	1	--	--	--	1	--
Pteridium aquilinum	4	23	25	52	46	60	5	--	--	--	2	--	1	--	2	--	--	--	--	--	--	--	--	--	--	--	1	--
Ephedra viridis-type	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Taxus canadensis	--	--	1	--	1	--	1	--	2	--	--	--	--	2	--	--	--	--	--	--	1	3	--	--	--	--	--	--	--
Abies balsamea	--	1	2	3	1	16	1	11	1	3	5	1	2	--	1	1	1	--	1	--	--	--	--	--	--	1	--	--	--
Tsuga	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Picea	4	3	4	10	6	44	30	251	192	374	270	242	236	266	316	218	284	303	324	257	308	266	357	328	178	362	251	151	84
Larix laricina	--	1	4	3	2	8	3	7	10	16	8	5	10	23	15	10	15	16	16	13	12	11	13	15	13	22	19	3	--
Pinus strobus-type	3	10	2	10	2	15	1	1	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pinus banksiana/resinosa-type	4	56	27	87	2	188	95	11	2	--	--	--	1	1	--	--	--	1	--	--	--	--	--	--	--	1	--	--	--
Pinus undifferentiated	82	322	278	506	412	844	232	22	7	4	1	3	4	4	2	--	1	2	2	1	--	1	2	--	2	4	4	1	2
Juniperus/Thuja	3	7	--	--	3	12	6	11	19	36	21	24	31	43	81	40	60	102	48	46	44	35	18	19	14	22	17	13	3
Typha latifolia	2	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	--	--	--	--	--
Sparganium-type	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Potamogeton (Coleogeton)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	1	--	--
Potamogeton (Eupotamogeton)	22	9	2	6	1	6	2	6	1	2	3	1	2	17	13	6	16	22	9	20	9	10	15	12	6	10	10	18	3
Gramineae	47	53	12	17	5	22	13	18	14	23	23	11	38	36	39	12	20	15	18	12	18	6	19	9	9	8	9	9	1
Cyperaceae	19	20	5	14	9	13	14	29	37	38	46	31	38	35	41	19	42	39	37	30	43	35	59	59	48	64	49	85	267
Tofieldia glutinosa	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	1	--	5	16
Allium	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Salix	1	7	4	2	4	3	2	10	13	19	13	12	13	13	15	3	4	5	4	5	10	2	6	9	4	6	5	9	5
Populus tremuloides-type	4	13	19	8	31	19	18	26	46	23	11	11	21	29	75	17	9	26	7	52	25	11	5	2	2	4	1	3	--
Populus balsamifera	--	1	--	1	3	12	2	11	22	43	29	16	18	29	36	28	37	18	26	33	39	19	56	7	7	7	8	12	5
Juglans cf. cinerea	1	5	1	3	6	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	--	--
Juglans cf. nigra	--	--	--	1	--	--	--	--	--	--	1	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	1	--
Carya	1	5	4	10	5	2	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--	--	2	--	--	--	--	--
Corylus	4	4	4	2	6	9	3	5	5	1	6	4	4	5	7	3	3	1	3	3	2	1	--	--	2	--	--	1	1
Ostrya/Carpinus	14	21	15	25	16	13	7	18	13	14	8	3	11	17	29	12	13	8	13	5	12	3	5	6	3	8	7	7	--
Betula	11	18	19	37	47	139	41	80	63	56	45	12	18	22	27	6	8	2	8	4	4	1	2	7	2	9	8	20	1
Alnus rugosa	10	18	20	27	14	32	18	20	27	22	23	6	11	4	3	--	5	1	1	--	--	1	1	4	2	6	2	1	--
Castanea	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Quercus	33	57	30	44	50	39	24	36	18	19	19	8	14	10	26	14	15	20	12	16	11	13	17	15	9	10	6	10	--
Ulmus	34	71	65	92	64	92	26	29	17	14	6	4	7	15	21	6	4	6	7	11	6	4	6	4	1	3	--	1	--
Celtis occidentalis	--	--	--	--	--	3	1	--	--	--	--	--	--	--	1	--	--	--	1	--	1	--	1	--	--	1	--	--	--
Morus rubra	--	3	1	3	1	1	--	--	--	--	--	--	--	--	2	--	1	1	1	1	2	1	1	--	--	--	--	--	--
Humulus lupulus	--	1	--	2	--	2	--	--	1	--	1	1	2	4	2	2	2	1	1	1	3	4	3	3	1	5	4	4	1
Urtica-type	--	4	1	5	2	5	1	3	7	5	1	5	12	9	14	10	11	25	13	13	12	9	6	7	5	9	8	20	5
Laportea-type	--	--	1	2	3	2	1	1	--	1	1	2	--	1	3	4	3	9	4	3	6	3	3	1	4	3	--	4	--
Rumex cf. mexicanus	--	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Polygonum amphibium-type	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chenopodium-type	7	6	1	6	3	8	3	--	1	4	4	2	9	8	6	5	3	2	4	2	3	3	4	--	2	5	1	1	1
Sarcobatus vermiculatus	2	1	--	--	--	--	--	1	--	--	--	--	1	1	--	--	--	--	1	--	--	--	1	--	--	--	--	--	--
Nuphar	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ranunculus-type	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--
Thalictrum cf. dioicum	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Thalictrum confine-type	--	--	--	--	--	--	--	--	1	--	2	1	1	--	--	--	1	1	1	1	--	--	--	1	--	--	1	--	--
Thalictrum cf. dasycarpum	--	--	--	--	--	1	--	--	--	1	--	--	1	2	2	--	1	2	--	--	3	1	1	3	1	1	2	--	1	--
Cruciferae	--	--	1	1	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
cf. Penthorum sedoides	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
cf. Heuchera richardsonii	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Platanus occidentalis	1	8	1	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	1	1	--	--	1	--	--	--	--	--
Rosaceae	--	--	--	2	2	--	1	--	--	1	1	--	1	--	1	--	1	1	1	1	1	1	4	1	--	--	2	--	--
Petalostemum candidum-type	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Hedysarum	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--
Xanthoxylum americanum	--	1	--	--	--	1	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Euphorbia (Chamaesyce)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
Rhus cf. radicans	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer spicatum	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer saccharum	1	2	3	7	3	7	2	1	--	--	--	1	--	--	--	--	--	--	--	--	--	1	--	--	--	1	--	1	--
Acer saccharinum-type	--	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer negundo	--	1	2	--	--	2	1	5	1	2	4	1	2	4	1	1	--	1	--	1	1	1	2	2	2	3	3	4	2
Rhamnus alnifolia	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Vitis	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--
Tilia americana	1	1	1	2	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Elaeagnus commutata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--
Shepherdia canadensis	--	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--	2	1	--	--	--	1	--	1	--	2	--	--
Myriophyllum exalbescens-type	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Hippuris	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
cf. Sium suave	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Umbelliferae undifferentiated	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

REFERENCES CITED

American Commission on Stratigraphic Nomenclature, 1961, Code of stratigraphic nomenclature: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, p. 645-665.

Andersen, S. Th., 1954, A late-glacial pollen diagram from southern Michigan, U.S.A.: Danmarks Geologiske Undersøgelse, ser. 2, no. 80, p. 140-155.

———— 1961, Vegetation and its environment in Denmark in the early Weichselian Glacial: Danmarks Geologiske Undersøgelse, ser. 2, no. 75, 175 p.

Arnold, J. R., and Libby, W. F., 1951, Radiocarbon dates: Science, v. 113, p. 111-120.

Artist, R. C., 1939, Pollen spectrum studies on the Anoka sand plain in Minnesota: Ecol. Monographs, v. 9, p. 493-535.

Bakusis, E. V., and Hansen, H. L., 1959, A provisional assessment of species synecological requirements in Minnesota forests: Minn. Forestry Notes 84, 2 p.

———— 1960, Use of ecographs in analyzing species-environmental relationships in forest communities: Minn. Forestry Notes 91, 2 p.

———— 1962a, Ecographs of shrubs and other undergrowth species of Minnesota forest communities: Minn. Forestry Notes 117, 2 p.

———— 1962b, Ecographs of herb species of Minnesota forest communities: Minn. Forestry Notes 118, 2 p.

Bertsch, Andreas, 1961, Untersuchungen an rezenten und fossilen Pollen von Juniperus: Flora, v. 150, no. 4, p. 503-513.

Beug, H.-J., 1961, Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete: Stuttgart, Gustav Fischer, 63 p.

Broecker, W. S., and Farrand, W. R., 1963, Radiocarbon age of the Two Creeks forest bed, Wisconsin: Geol. Soc. America Bull., v. 74, no. 6, p. 795-802.

Buell, M. F., and Buell, H. F., 1941, Surface level fluctuations in Cedar Creek Bog, Minnesota: Ecology, v. 22, p. 317-321.

Chu, K. L., 1948, The upland plant communities of Cedar Creek Forest, Anoka County, Minnesota: unpublished M.S. thesis, University of Minnesota.

Churchill, D. M., and Sarjeant, W. A. S., 1962, Freshwater microplankton from Flandrian (Holocene) peats of southwestern Australia: Grana Palynologica, v. 3, no. 3, p. 29-53.

Clayton, Lee, 1961, Late Wisconsin mollusca from ice-contact deposits in Logan County, North Dakota: N. D. Acad. Sci. Proc., v. 15, p. 11-18.

Clements, F. E., 1936, Nature and structure of the climax: Jour. Ecology, v. 24, p. 252-284.

Conway, Verona M., 1949, The bogs of central Minnesota: Ecol. Monographs, v. 19, p. 173-206.

Cooper, W. S., 1935, The history of the upper Mississippi River in late Wisconsin and postglacial time: Minn. Geol. Survey Bull. 26, 116 p.

Cooper, W. S., and Foot, Helen, 1932, Reconstruction of a late-Pleistocene biotic community in Minneapolis, Minnesota: Ecology, v. 13, p. 63-72.

Curtis, J. T., 1959, The vegetation of Wisconsin: Madison, Wis., Univ. of Wis. Press, 655 p.

Cushing, E. J., 1962, Redeposited pollen in late-glacial sediments in east-central Minnesota [abs.] : Pollen et Spores, v. 4, no. 2, p. 340.

Cushing, E. J., and Wright, H. E., Jr., 1963, Piston corers for lake sediments: unpublished manuscript.

Dansereau, Pierre, 1957, Biogeography: an ecological perspective: New York, Ronald Press, 394 p.

Daubenmire, R. F., 1936, The "Big Woods" of Minnesota: its structure and relation to climate, fire, and soils: Ecol. Monographs, v. 6, p. 233-268.

Davis, Margaret B. (Margaret S. Bryan), 1954, Interglacial pollen spectra from Greenland: Danmarks Geologiske Undersøgelse, ser. 2, no. 80, p. 65-72.

———— 1958, Three pollen diagrams from central Massachusetts: Am. Jour. Sci., v. 256, p. 540-570.

———— 1961a, The problem of rebedded pollen in late-glacial sediments at Taunton, Massachusetts: Am. Jour. Sci., v. 259, p. 211-222.

———— 1961b, Pollen diagrams as evidence of late-glacial climatic change in southern New England: N. Y. Acad. Sci. Ann., v. 95, art. 1, p. 623-631.

Deevey, E. S., Jr., 1951, Late-glacial and post-glacial pollen diagrams from Maine: Am. Jour. Sci., v. 249, p. 177-207.

Drury, W. H., Jr., 1956, Bog flats and physiographic processes in the upper Kuskokwim River region, Alaska: Contrib. Gray Herbarium Harvard Univ., no. 178, 130 p.

Eddy, Samuel, 1930, The fresh-water armored or thecate dinoflagellates: Trans. Am. Microscop. Soc., v. 49, p. 277-321.

Erdtman, Gunnar, 1957, Pollen and spore morphology/plant taxonomy: Gymnospermae, Pteridophyta, Bryophyta: Stockholm, Almqvist and Wiksell, 151 p.

Farnham, R. S., 1956, Geology of the Anoka sand plain, in Geol. Soc. America Guidebook 1956 Ann. Meeting, Minneapolis: Field Trip no. 3, p. 53-64.

Farnham, R. S., Simonson, G. H., Johnson, W., and Hermanson, H. P., 1958, Soil survey of Isanti County, Minnesota: U. S. Dept. Agric. Soil Conservation Service, ser. 1953, no. 1, 60 p.

Fernald, M. L., 1950, Gray's manual of botany, eighth edition: New York, American Book Co., 1632 p.

Flint, R. F., 1957, Glacial and Pleistocene geology: New York, John Wiley, 553 p.

Flint, R. F., and Deevey, E. S., Jr., 1951, Radiocarbon dating of late-Pleistocene events: Am. Jour. Sci., v. 249, p. 257-300.

Frey, D. G., 1959, The Two Creeks interval in Indiana pollen diagrams: Invest. Indiana Lakes and Streams, v. 4, no. 4, p. 131-139.

Fries, Magnus, 1962, Pollen profiles of late Pleistocene and recent sediments from Weber Lake, Minnesota: Ecology, v. 43, p. 295-308.

Fries, Magnus, Wright, H. E., Jr., and Rubin, Meyer, 1961, A late Wisconsin buried peat at North Branch, Minnesota: Am. Jour. Sci., v. 259, p. 679-693.

Gleason, H. A., 1939, The individualistic concept of the plant association: Am. Midland Naturalist, v. 21, p. 92-108.

Good, Ronald, 1953, The geography of the flowering plants: New York, Longmans, Green, 452 p.

Hartz, N., 1912, Allerød-Gytje und Allerød-Mull: Meddelelser fra Dansk Geologisk Forening, v. 4, p. 85-92.

Heusser, C. J., 1960, Late-Pleistocene environments of North Pacific North America: New York, Am. Geographical Soc., 308 p.

Hultén, Eric, 1962, The circumpolar plants, I. Vascular cryptogams, conifers, monocotyledons: Kungl. Svenska Vetenskapsakademiens Handl., ser. 4, v. 8, no. 5, 275 p.

Iversen, Johs., 1936, Sekundäres Pollen als Fehlerquelle: Danmarks Geologiske Undersøgelse, ser. 4, v. 2, no. 15, 24 p.

———— 1942, En pollen analytisk tidsfaestelse af ferskvandslagene ved Nørre Lyngby: Dansk Geologisk Forening Meddelelser, v. 10, p. 130-151.

———— 1947, Plantevaekst, dyreliv og klima i det senglaciale Danmark: Geologiska Föreningens i Stockholm Förhandl., v. 69, p. 67-78.

———— 1954, The late-glacial flora of Denmark and its relation to climate and soil: Danmarks Geologiske Undersøgelse, ser. 2, no. 80, p. 87-119.

Iversen, Johs., and Troels-Smith, J., 1950, Pollenmorfologiske definitioner og typer: Danmarks Geologiske Undersøgelse, ser. 4, v. 3, no. 8, 54 p.

Jelgersma, Saskia, 1962, A late-glacial pollen diagram from Madelia, south-central Minnesota: Am. Jour. Sci., v. 260, p. 522-529.

Jessen, Knud, Andersen, S. Th., and Farrington, A., 1959, The interglacial deposit near Gort, Co. Galway, Ireland: Roy. Irish Acad. Proc., v. 60, sect. B, no. 1, 77 p.

Krog, Harald, 1954, Pollen analytical investigation of a C^{14}-dated Allerød section from Ruds Vedby: Danmarks Geologiske Undersøgelse, ser. 2, no. 80, p. 120-139.

Jørgensen, Svend, 1954, A pollen analytical dating of Maglemose finds from the bog Aamosen, Zealand: Danmarks Geologiske Undersøgelse, ser. 2, no. 80, p. 159-187.

Lindeman, R. L., 1941a, The developmental history of Cedar Creek Bog, Minnesota: Am. Midland Naturalist, v. 25, no. 1, p. 101-112.

———— 1941b, Seasonal food-cycle dynamics in a senescent lake: Am. Midland Naturalist, v. 26, p. 636-673.

———— 1942, Experimental simulation of winter anaerobiosis in a senescent lake: Ecology, v. 23, p. 1-13.

Livingstone, D. A., 1955, A lightweight piston sampler for lake deposits: Ecology, v. 36, p. 137-139.

Livingstone, D. A., and Livingstone, B. G. R., 1958, Late-glacial and postglacial vegetation from Gillis Lake in Richmond County, Cape Breton Island, Nova Scotia: Am. Jour. Sci., v. 256, p. 341-359.

Maher, L. J., Jr., 1962, Ephedra pollen in late-glacial and post-glacial sediments of the Great Lakes region and its probable significance [abs.]: Geol. Soc. America Spec. Paper 73.

Maloney, Norma A., 1961, Comparative morphology of spores of the ferns and fern allies of Minnesota: Ph.D. thesis, Univ. of Minnesota, 187 p. Ann Arbor, Mich.: Univ. Microfilms (Dissertation Abstr., v. 22, p. 1805).

Martin, P. S., 1958a, Pleistocene ecology and biogeography of North America, in Zoogeography: New York, Am. Assoc. Adv. Sci., p. 375-420.

———— 1958b, Taiga-tundra and the full-glacial period in Chester County, Pennsylvania: Am. Jour. Sci., v. 256, p. 470-502.

Martin, P. S., Schoenwetter, James, and Arms, B. C., 1961, Southwestern palynology and prehistory: the last 10,000 years: Tucson, Univ. of Arizona Geochronology Laboratories, 119 p.

Maycock, P. F., and Curtis, J. T., 1960, The phytosociology of boreal conifer-hardwood forests of the Great Lakes region: Ecol. Monographs, v. 30, p. 1-35.

Moore, J. W., 1952, The flora of the Cedar Creek Forest area: Minn. Acad. Sci. Proc., v. 20, p. 10-19.

Müller-Stoll, W., 1956, Über das Verhalten der Exine nonaperturater Angiospermen-Pollen bei Quellung und Keimung: Grana Palynologica, v. 1, no. 2, p. 38-58.

Nordmann, V., 1928, Lateglacial and postglacial periods, in Summary of the geology of Denmark: Danmarks Geologiske Undersøgelse, ser. 5, no. 4, p. 120-124.

Nye, J. F., 1960, The response of glaciers and ice-sheets to seasonal and climatic changes: Proc. Roy. Soc. London, ser. A, v. 256, p. 559-584.

Ogden, J. G., III, 1963, The Squibnocket Cliff peat: radiocarbon dates and pollen stratigraphy: Am. Jour. Sci., v. 261, p. 344-353.

Patten, H. L., 1959, A postglacial pollen diagram from Lake Carlson, Dakota County, southern Minnesota: unpublished M.S. thesis, Univ. of Minnesota, 35 p.

Pierce, R. L., 1954, Vegetation cover types and land use history of the Cedar Creek Natural History Reservation, Anoka and Isanti Counties, Minnesota: unpublished M.S. thesis, Univ. of Minnesota, 137 p.

———— 1957, Minnesota Cretaceous pine pollen: Science, v. 125, p. 26.

———— 1961, Lower Upper Cretaceous plant microfossils from Minnesota: Minn. Geol. Survey Bull. 42, 86 p.

Potzger, J. E., 1944, Pollen frequency of Abies and Picea in peat: a correction on some published records from Indiana bogs and lakes: Butler Univ. Botanical Studies, v. 6, p. 123-130.

———— 1946, Phytosociology of the primeval forest in central-northern Wisconsin and upper Michigan, and a brief post-glacial history of the lake forest formation: Ecol. Monographs, v. 16, p. 211-250.

Rand, Patricia J., 1953, The plant communities and history of the Carlos Avery Game Refuge, Anoka County, Minnesota: unpublished M.S. thesis, Univ. of Minnesota, 168 p.

Rowe, J. S., 1956, Uses of undergrowth plant species in forestry: Ecology, v. 37, p. 461-473.

Rowley, J. R., and Dahl, A. O., 1956, Modifications in design and use of the Livingstone piston sampler: Ecology, v. 37, p. 849-851.

Rubin, Meyer, and Alexander, Corrinne, 1958, U. S. Geological Survey radiocarbon dates IV: Science, v. 127, p. 1476-1487.

Scoggan, H. J., 1957, Flora of Manitoba: Nat. Mus. Canada Bull. 140, 619 p.

Steeves, M. W., and Barghoorn, E. S., 1959, The pollen of Ephedra: Jour. Arnold Arboretum, v. 40, no. 3, p. 221-255.

Swain, F. M., 1956, Stratigraphy of lake deposits in central and northern Minnesota: Am. Assoc. Petroleum Geologists, v. 40, no. 4, p. 600-653.

Swain, F. M., and Prokopovich, N., 1954, Stratigraphic distribution of lipoid substances in Cedar Creek Bog, Minnesota: Geol. Soc. America Bull., v. 65, p. 1183-1198.

Swain, F. M., Blumentals, A., and Millers, R., 1959, Stratigraphic distribution of amino acids in peats from Cedar Creek Bog, Minnesota, and Dismal Swamp, Virginia: Limnology and Oceanography, v. 4, no. 2, p. 119-127.

Thomas, B. O., 1959, The biodynamics of sedimentation in Horseshoe Lake, Isanti County, Minnesota: Ph.D. thesis, Univ. of Minnesota, 161 p. Ann Arbor, Mich.: Univ. Microfilms (Dissertation Abstr., v. 20, p. 1496).

Ting, W. S., 1961, On some pollen of Californian Umbelliferae: Pollen et Spores, v. 3, no. 2, p. 189-199.

Troels-Smith, J., 1941, Geological dating of a reindeer antler hammer from Vedbaek: Acta Archaeologica, v. 12, fasc. 3, p. 135-144.

———— 1955, Karakterisering af løse jordarter: Danmarks Geologiske Undersøgelse, ser. 4, v. 3, no. 10, 73 p.

Tuthill, S. J., 1961, A molluscan fauna and late Pleistocene climate in southeastern North Dakota: N. D. Acad. Sci. Proc., v. 15, p. 19-26.

Ueno, Jitsuro, 1958, Some palynological observations of Pinaceae: Osaka City Univ. Inst. Polytechnics Jour., ser. D, v. 9, p. 163-178.

Vallentyne, J. R., 1955, A modification of the Livingstone piston sampler for lake deposits: Ecology, v. 36, p. 139-141.

Vallentyne, J. R., and Swabey, Y. S., 1955, A reinvestigation of the history of lower Linsley Pond, Connecticut: Am. Jour. Sci., v. 253, p. 313-340.

Weertman, J., 1961, Stability of ice-age ice sheets: Jour. Geophysical Research, v. 66, p. 3783-3792.

West, R. G., 1961, Late- and postglacial vegetational history in Wisconsin, particularly changes associated with the Valders readvance: Am. Jour. Sci., v. 259, p. 766-783.

Whitehead, D. R., 1963, Pollen morphology in the Juglandaceae, I: pollen size and pore number variation: Jour. Arnold Arboretum, v. 44, p. 101-110.

Wilson, I. T., and Potzger, J. E., 1943, Pollen records from lakes in Anoka County, Minnesota: a study of methods of sampling: Ecology, v. 24, p. 382-392.

Winter, T. C., 1961, A pollen analysis of Kirchner Marsh, Dakota County, Minnesota: unpublished M.S. thesis, Univ. of Minnesota, 35 p.

———— 1962, Pollen sequence at Kirchner Marsh, Minnesota: Science, v. 138, no. 3539, p. 526-528.

Wright, H. E., Jr., 1956, Sequence of glaciation in eastern Minnesota, in Geol. Soc. America Guidebook 1956 Ann. Meeting, Minneapolis: Field Trip no. 3, p. 1-24.

———— 1962, Late Wisconsin glacial and vegetational sequence in Minnesota [abs.]: Geol. Soc. America Spec. Paper 73.

Wright, H. E., Jr., and Rubin, Meyer, 1956, Radiocarbon dates of Mankato drift in Minnesota: Science, v. 124, no. 3223, p. 625-626.

Wright, H. E., Jr., Winter, T. C., and Patten, H. L., 1962, Two pollen diagrams from southeastern Minnesota: problems in the regional late- and post-glacial vegetational history: unpublished manuscript.